

Appendix C

**Attachment to
NR:IBO-05/023**

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NR:IBO-05/023**

**Evaluation of Naval Reactors Facility Radioactive Waste
Disposed of at the Radioactive Waste Management Complex**

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I. Background on the Naval Reactors Facility

In 1948, the Atomic Energy Commission (AEC) contracted with Westinghouse Electric to design, build, operate, and test a prototype pressurized-water, Naval nuclear propulsion plant known as the Submarine Thermal Reactor Mark I or S1W. The plant was a prototype for the first nuclear-powered submarine USS NAUTILUS (SSN 571). S1W construction was completed in 1953 at the AEC National Reactor Testing Station (NRTS) in Idaho. S1W reached criticality on March 30, 1953 becoming the first reactor to produce significant quantities of useful nuclear power in the world. Later in 1953, S1W achieved full design power and commenced a successful 96-hour sustained full-power run that simulated a submerged crossing of the Atlantic Ocean. During operations of the second S1W reactor core in 1955, a 66-day continuous full power run was performed, which could have propelled a submarine at high speed twice around the globe. Over its lifetime, S1W was used to train over 13,000 Navy officers, enlisted operators, and civilian students. S1W was permanently shutdown in October 1989 after 36 years of operation of which the last 22 years were performed with a single core establishing a longevity record.

In 1956, construction began on the A1W prototype plant. A1W was the first nuclear powered surface ship prototype and consisted of two pressurized water reactors. The plant was built as a prototype for the aircraft carrier USS ENTERPRISE (CVN 65), which was the first nuclear-powered aircraft carrier. The prototype provided realistic training for the students in an environment nearly identical to what they would encounter within an actual carrier. Power operations at A1W commenced in October of 1958. A1W was the first nuclear propulsion plant to have two reactors powering one ship propeller shaft through a single-gear turbine propulsion unit. Over the life of the plant, new cores and equipment replaced many of the original A1W components. On January 26, 1994, the A1W prototype plant was shut down after more than 35 years of successful testing and training activities. More than 14,500 Navy and civilian students were trained at A1W during the 35 years of operation.

The third prototype constructed at NRF was the S5G prototype. This pressurized water reactor prototype first operated in 1965. S5G was a prototype of the USS NARWHAL (SSN 671) submarine and had the capability to operate in either a forced circulation or a natural circulation mode. In the natural circulation mode, cooling water flowed through the reactor by thermal circulation; pumps were not needed. This reduced plant noise level, which is vital to submarine stealth. To verify the new design concepts would work in an operational submarine, the prototype was built in a submarine hull section capable of simulating the rolling motion of a ship at sea. On May 1, 1995, the S5G prototype was shut down after 30 years of successful testing and training activities. Approximately 12,000 Navy and civilian students were trained at S5G during the 30 years of operation.

The Exposed Core Facility (ECF) has examined and tested fuel from nuclear-powered warships, prototype plants, and the Shippingport Atomic Power Station. In addition, ECF has examined specimens of irradiated fuel that were placed in a test reactor, such as the Advanced Test Reactor. The information from detailed study of this fuel has enabled tremendous improvements to U.S. Naval and commercial reactor designs. One result is that the endurance of Naval nuclear propulsion plants has been increased from two years for the first core in NAUTILUS to the entire 30+ year lifetime of the submarines under construction today. Most importantly, this research has dramatically improved the warfighting capabilities of America's nuclear-powered warships.

ECF was constructed in 1957, and originally consisted of a water pool and a shielded cell with a connecting transfer canal. The facility has been modified as necessary to accomplish the expanding mission of the facility including the addition of three more water pools, several shielded cells, and other capabilities dictated by the nature of the work performed. The water pools permit visual observation of naval spent nuclear fuel during handling and inspection while shielding workers from radiation. The shielded cells are used for operations which must be performed dry.

II. Purpose of This Evaluation

In reference (a), the DOE Idaho Operations Office (DOE-ID) requested Naval Reactors, Idaho Branch Office (NR/IBO) assistance in resolving issues associated with characterizing the waste inventory for the Radioactive Waste Management Complex (RWMC) located at the Idaho National Engineering and Environmental Laboratory (INEEL). The requested information included the radioactivity inventory of various NRF radioactive wastes sent to the RWMC as well as information about the physical and chemical form of that waste. Of particular interest were waste forms that might have included small amounts of irradiated fuel materials since several RWMC burial records had been found which indicated the presence of irradiated fuel materials. Also of particular interest was information about waste forms that may be considered mobile (i.e., liquid, sludge, irradiated saw fines, and chips) and information which might be of a safety concern for investigation or remediation of RWMC. This evaluation is focused on those specific issues mentioned in reference (a) with additional information provided as requested in subsequent correspondence from DOE-ID (references b, c, and d).

With the many and varied types of work performed at NRF over the past half century, a wide variety of radioactive wastes have been generated and disposed of at RWMC. The largest amount of radioactivity in NRF waste has been associated with non-fuel structural material removed from spent fuel assemblies. This material consists of corrosion resistant metals such as stainless steel and inconel that have been highly irradiated in reactor cores. Since the beginning of NRF operations, this activated structural material has been removed from Naval fuel assemblies during the preparation for examination. This highly activated structural material has been and continues to be disposed of at RWMC. The radioactivity content of this waste stream has been reviewed and recalculated several times at the request of DOE-ID as more radionuclides have become of interest in performing environmental evaluations of RWMC. For this review, Chlorine-36 (Cl-36) was evaluated, which had not previously been evaluated in this waste stream.

Compared to the irradiated structural material and the irradiated fuel material waste streams, the remainder of NRF waste streams contained much less overall radioactivity. These waste streams would have included the radioactive waste associated with operation and maintenance of the NRF prototype reactor plants as well as the waste streams associated with the Expended Core Facility.

II.A. Summary of NRF Waste Disposed of at RWMC

Summary tables of the total radioactivity in NRF radioactive waste sent to the RWMC for the time period assessed are provided in Section V. As noted above, the largest amount of radioactivity in NRF waste has been associated with non-fuel structural material removed from spent fuel assemblies. This material consists of corrosion resistant metals such as stainless steel and inconel that have been highly irradiated in reactor cores. The total amount of radioactivity associated with this waste stream has not changed significantly from previous evaluations.

In some cases, examination of fuel assemblies at ECF resulted in waste containing small amounts of irradiated fuel materials. Prior to 1971, these wastes were disposed of at the RWMC at INEEL in accordance with the radioactive waste requirements at that time. NRF has carefully studied the available records from the 1950s and 1960s to generate the best estimate of the small amount of irradiated fuel materials buried at RWMC.

For Naval fuel materials with highly enriched uranium, only 0.205 kilogram of this uranium were determined to be in the NRF radioactive waste by this evaluation. This is less than one hundredth of one percent (less than 0.01%) of the amount of uranium in all of the Naval spent fuel that has been examined at NRF. This very small amount of enriched uranium was in the form of various types of fuel examination wastes. Highly enriched uranium was a valuable resource in the 1950s and 1960s.

The Idaho Chemical Processing Plant (ICPP, currently called INTEC) was located on the INEEL and processed spent highly enriched uranium fuels to recover the U-235 from these fuels. ICPP provided a ready outlet for any unneeded irradiated highly enriched uranium at NRF. Thus only very small amounts of finely divided or dissolved fuel materials were included in the radioactive waste sent to RWMC.

Another type of fuel examined at ECF was the natural uranium blanket fuel from the Shippingport Atomic Power Station. This fuel is described in more detail in Section III. Irradiated natural uranium fuel, with its much lower concentration of fissionable U-235, is much less radioactive than irradiated fuel with highly enriched uranium. Irradiated natural uranium fuels had some residual value in the 1960s both in the plutonium that could be extracted by chemical processing and the residual partially depleted uranium. However, there was no processing capability at INEEL for irradiated natural uranium fuel. There was capacity for natural uranium fuel processing at Hanford. Over 95% of the irradiated Shippingport natural uranium blanket fuel examined at ECF was subsequently shipped to Hanford for processing in 1966. 219 kilograms of this natural uranium fuel material was considered to be uneconomical for shipment to Hanford and was disposed of as radioactive waste at RWMC. This natural uranium fuel material did not consist of entire fuel assemblies, but rather smaller pieces of fuel assemblies or other waste generated during the fuel examination process.

In 1970, the Atomic Energy Commission modified the requirements for low-level waste to preclude the burial of transuranic radionuclides above a specified concentration. (The Nuclear Regulatory Commission adopted comparable limits for commercial licensed disposal sites in 1983.) Accordingly, since 1970 NRF has not disposed of waste at RWMC that contained irradiated fuel materials.

There are several other types of radioactive waste materials that would not be permitted to be disposed of at RWMC under current requirements for which there were no restrictions in the 1950s and 1960s. As requested by DOE-ID, this evaluation includes information on several of these types of materials, including radioactive waste in liquid or sludge form, radioactive oil, and radioactive zirconium in the form of finely divided chips.

III. Investigation of Wastes with Small Amounts of Irradiated Fuel Materials

III.A. Evaluation of Receipt and Disposition of Shippingport Fuel

III.A.1 Background on the Shippingport Pressurized Water Reactor

The Shippingport Atomic Power Station was the Nation's first commercial nuclear power reactor. Initial operation was in December 1957. Shippingport was a pressurized water reactor. The first two reactor cores were "seed and blanket" reactor cores. The seed assemblies had highly enriched uranium, and the blanket assemblies had natural uranium. The first core (PWR-1) had three partial refuelings where the expended seed fuel was removed and replaced with new seed fuel. Selected blanket fuel also was removed and replaced during the seed refuelings. The final defueling of PWR-1 included the removal of all seed and blanket fuel. The second core (PWR-2) included one refueling, where the seed fuel was removed and replaced. The defueling included the removal of all seed and blanket fuel in preparation for the light water breeder reactor. (reference e)

The seed fuel associated with PWR-1 was referred to as Seed 1, Seed 2, Seed 3, and Seed 4, which correlates with the initial seed loading and the replacement seed fuel at each partial refueling. Figure 1 in Attachment 1 shows the arrangement of the PWR-1 core. There were 32 seed assemblies. Each seed assembly included four subassemblies (128 total) and each subassembly

contained 15 fuel elements (1920 total). Figure 2 in Attachment 1 shows a cross section of a seed subassembly. The as-built Uranium-235 (U-235) loading for Seed 1 was 75 kilograms (Kg) of U-235 while Seeds 2 through 4 had 90 Kg of U-235. Operations with Seed 1 occurred between 1957 and 1959; Seed 2, between 1960 and 1961; Seed 3, between 1961 and 1962; and Seed 4, between 1963 and 1964. (reference f and n)

In addition to the seed fuel, two test assemblies containing highly enriched uranium were placed into PWR-1. These test assemblies, known as Special Oxide Assembly Prototype (SOAP) I and II, replaced blanket fuel assemblies. SOAP-I was placed in the core during the partial refueling for replacement of Seed 2 with Seed 3. SOAP-II was placed in the core during the partial refueling for replacement of Seed 3 with Seed 4. Both SOAP assemblies were removed during the final defueling of PWR-1. (reference g)

The PWR-1 blanket fuel was made of natural uranium in the form of natural uranium dioxide pellets clad with zircaloy tubes. Figure 3 in Attachment 1 shows the arrangement of a PWR-1 blanket assembly. Each blanket assembly was made from seven stacked fuel bundles. Each fuel bundle was an array of short zircaloy tubes with natural uranium oxide pellets in the tubes. PWR-1 had space for 113 blanket assemblies. Each assembly contained seven fuel bundles (total of 791) and each bundle contained 120 short fuel rods (total of 94,920). The as-built natural uranium loading for the blanket fuel was approximately 12,850 Kg of natural uranium. (references e,g,h)

During each seed refueling of PWR-1, some blanket fuel assemblies were removed primarily for testing purposes to evaluate the performance of the blanket fuel. Most of the blanket fuel was not removed during the refuelings and remained in PWR-1 through all four seeds. During the Seed 1 replacement with Seed 2, two blanket fuel bundles and one blanket assembly were replaced and sent to ECF at NRF for testing purposes. During the Seed 2 replacement with Seed 3, three blanket assemblies were replaced and sent to NRF. The SOAP-I test assembly replaced one blanket assembly, while the other two blanket subassemblies were removed for testing purposes.

When Seed 3 was replaced with Seed 4, again three blanket assemblies were replaced and sent to NRF. The SOAP-II test assembly replaced one blanket assembly and the Special Assembly of Blanket Rod Elements (SABRE) assembly replaced another. The SABRE assembly was a natural uranium blanket assembly where the fuel rods extended the full height of the core rather than being subdivided into smaller stacked bundles. During the final defueling of PWR-1, all the blanket and seed fuel was removed.

The PWR-2 core was also a seed and blanket core with 20 seed assemblies and 77 blanket assemblies. The core had one refueling where Seed 1 was replaced with Seed 2 fuel. The first seed operated between 1965 and 1969, while the second operated between 1969 and 1974. The as-built U-235 loading of PWR-2 Seed 1 was 336 Kg U-235, and Seed 2 was 390 Kg U-235. The blanket fuel had an as-built natural uranium loading of 17,100 Kg natural uranium. (references i,j)

One blanket assembly location in PWR-2 was occupied by a Multipurpose Extended Life Blanket Assembly (MELBA). The purpose of the MELBA assembly was to determine the effect of extended irradiation on PWR-1 blanket bundles. Eighteen PWR-1 blanket bundles were retained for use in the MELBA. Nine bundles were inserted in the MELBA assembly and irradiated during PWR-2 Seed 1 operation. Nine bundles were retained as backup bundles. During the PWR-2 partial refueling, the MELBA assembly was removed. Three bundles were replaced with backup bundles, and the MELBA assembly was reinserted for operation with PWR-2 Seed 2. One regular blanket assembly also was removed for examination and replaced during the partial refueling. All seed and blanket fuel was removed from the Shippingport reactor following completion of PWR-2 operation in 1974. (references i,j,k)

III.A.2 Scope of the Shippingport Fuel Evaluation

Examination of spent fuel at ECF can involve the testing of small pieces that are removed from the fuel. Some pieces may also undergo destructive evaluation, such as chemical dissolution and measurement of the amount of individual radionuclides in those pieces. (reference p) In some cases, these examinations resulted in waste containing small amounts of irradiated fuel materials. Prior to 1970, some of these wastes were disposed of at the RWMC at INEEL in accordance with the radioactive waste requirements at that time.

In reference (a), the DOE-ID requested NR/IBO assistance in resolving issues associated with characterizing the waste inventory for the RWMC. One area of particular interest in this request was determining the amount and curie content of irradiated fuel materials from the Shippingport plant which was disposed of at RWMC. DOE-ID requested the following information regarding the Shippingport fuel:

- (1) A complete review of shipping records and documentation of findings.
- (2) An assessment of the initial Shippingport fuel mass and an accounting of its ultimate fate.
- (3) A review of the Shippingport seed fuel.

III.A.3 Receipt of Shippingport Fuel at ECF

All Shippingport PWR-1 and PWR-2 Seed fuel as well as the highly enriched uranium SOAP test assemblies were shipped to the Expanded Core Facility (ECF) following the various seed refuelings and defuelings. Attachment 2 provides a listing of all PWR-1 seed fuel receipts at ECF.

Only a portion of the natural uranium blanket fuel assemblies from PWR-1 was sent to ECF for examination. Attachment 3 provides a listing of all PWR-1 blanket fuel receipts at ECF. The 4330 kilograms of natural uranium in PWR-1 blanket fuel shipped to ECF were about one third of the total 12,850 kilograms of natural uranium in the PWR-1 blanket. The other two thirds of the blanket fuel were sent directly to Hanford.

All shipments of MELBA and PWR-2 seed and blanket fuel to ECF occurred after the change in burial requirements in 1970. (reference o) Therefore, there is no concern that any fuel materials from the PWR-2 fuel in ECF's possession, including the MELBA bundles, were disposed of at RWMC. All PWR-2 fuel that was not sent to the Idaho Chemical Processing Plant (ICPP, now the Idaho Nuclear Technology and Engineering Center or INTEC) for processing or to another off-site organization for testing and examination remains in storage at ECF. PWR-2 fuel receipts and disposition are therefore not discussed further in this evaluation.

III.A.4 Review of Waste Disposal Records

Previous record reviews by DOE-ID contractor personnel have found several "Waste Disposal and Authorization Forms" originating from ECF that have identified irradiated PWR fuel materials in the waste contents. A thorough review of NRF waste disposal records was performed to determine whether any additional PWR irradiated fuel material shipments to RWMC could be found.

Several sources of information were considered in the review of irradiated PWR-1 fuel materials that may have been sent to the RWMC. These sources included NRF RWMC shipping manifest disposal records, past letters, and monthly disposal reports. The NRF waste shipping manifests were verified to be nearly complete by the sequential numbering used during this time period for shipments sent from various facilities at NRF. For example, shipments from ECF in 1960 began with the number 69 (meaning there were 68 previous shipments from ECF prior to 1960) and were sequentially numbered to 934 through the end of 1965. In 1966, the sequential numbering was modified such that the first shipment for the year was E-1 ("E" for ECF, "S" for S1W, etc.) and shipments were sequentially numbered until the beginning of the next year. This numbering system helped verify the completeness of the shipping records. PWR-1 fuel material shipments from NRF would have originated from ECF. Beginning in 1970, those wastes defined as transuranic materials were not sent to RWMC for disposal.

Attachment 4 provides copies of all of the Waste Disposal and Authorization Forms (waste shipping manifests) to RWMC related to irradiated PWR fuel material. No additional irradiated fuel material shipments were found during this latest review other than those provided by the DOE-ID contractor. The Waste Disposal and Authorization Forms usually included descriptions, volumes, weight, container type, estimated curies, radiation levels, and various approvals for the waste shipment. All of the Waste Disposal and Authorization Forms manifests include a nuclear material accountability signature (referred to as an "SS" signature on the manifest) that was signed if fuel was part of the shipment. In general, the information provided on the manifests was accurate with the exception of the curie totals and radionuclide content. The listed radioactivity content varied widely for similar shipments, and thus cannot be considered reliable. The mass of nuclear material (i.e., uranium, plutonium, etc.) is likely to be accurate since these were based on fuel accountability requirements and were verified with signatures by those responsible for the nuclear material. Also, the listed masses are consistent with the listed content and do not indicate the same variation and inconsistencies as the curie content.

Attachment 5 lists the known shipments of PWR irradiated natural uranium fuel material to the RWMC and provides an estimate of the irradiated fuel material disposed at the RWMC based on the NRF shipping disposal manifests. A total of approximately 214 Kg of irradiated natural uranium is estimated to have been sent to the RWMC. A small fraction of this fuel, 5.48 Kg of uranium, was in a dissolved form absorbed in vermiculite. During testing and analysis at ECF, small quantities of material were dissolved in nitric and hydrofluoric acid. The remainder of the irradiated fuel material was listed as being in individual short rods or subassembly bundles of rods. While no information is available on the integrity of the cladding in these rods, it is likely that the cladding was intact in cases where subassembly bundles were disposed of (190 Kg uranium). In cases where individual rods were disposed of or bundles were incomplete or partially disassembled (18 Kg uranium), it would be appropriate to assume that the rod cladding is open to the immediate environment. Figure 4 in Attachment 1 shows the typical configuration of a PWR-1 rod.

As noted above, no additional shipments of irradiated PWR-1 fuel were identified during this review. In fact, the 214 Kg of irradiated natural uranium listed in Attachment 5 is approximately 16 Kg less than the 230 Kg total listed in the preliminary evaluation forwarded by the Naval Reactors Idaho Branch Office on March 6, 2002 (reference I). The reduction is due to the determination that a 16 Kg shipment documented in a nuclear material inventory reconciliation report for the second half of 1969

and first half of 1970 was actually unirradiated natural uranium rather than irradiated natural uranium. Shipments to RWMC of unirradiated natural uranium associated with Shippingport are included in Table 9 of Section III.C.

III.A.5 Material Balance for PWR-1 Seed and Blanket Fuel Received at ECF

As part of this review, a material balance was conducted to compare the amount of PWR-1 fuel that was received at ECF with the amount that was shipped out from ECF or is still in storage at ECF. Separate material balances were performed for the highly enriched uranium seed fuel and the natural uranium blanket fuel. One difficulty in performing such material balances was locating the specific fuel transfer records for PWR-1 fuel. Over its long history, ECF has received and transferred large amounts of nuclear fuel in a very large number of transactions. In addition to the Shippingport fuel, these transactions include the much larger amount of Naval spent fuel as well as a large number and variety of irradiated fuel test specimens. Fuel transfer records from the 1960's are not computerized, nor are they sorted by type of fuel such as PWR-1. Generally, these records are grouped by the site of origin for receipts and the destination site for transfers. Records of receipt of Shippingport PWR-1 fuel at ECF were relatively easy to locate because they came primarily from the Shippingport site at known times. Transfers of various types of fuel away from ECF went to a large number of places both on INEEL and off-INEEL. Known locations of off-INEEL transfers include the Bettis and Knolls Atomic Power Laboratories, Battelle Columbus Laboratory, Battelle Pacific Northwest Laboratory, other Hanford contractors, Chalk River in Canada, Oak Ridge National Laboratory, and the Savannah River Site. When looking for PWR-1 fuel transfer records, it has been necessary to concentrate the search on destinations where such fuel is known to have been sent and timeframes when such transfers were most likely to have occurred. Thus, it is possible that some records of PWR-1 transfers from ECF may not have been located among the large number of historical records. Such cases, if they exist, would tend to inflate the potential deficit of PWR-1 fuel in these material balances.

Another source of uncertainty in such material balances involves knowing precisely how much uranium was in a particular piece of PWR-1 fuel. While the as-built quantities of uranium in new PWR-1 fuel would be known within manufacturing tolerances, the amount of uranium remaining in irradiated fuel was less well known. One of the chief reasons for examining PWR-1 seed and blanket fuel was to determine the accuracy of calculations of how many fissions occurred in various parts of the core. Thus, the understanding of how much uranium would have been in individual parts of the PWR-1 core would have changed as a result of the examination. It is not clear that the amount of uranium listed for any particular piece would be the same when that piece was transferred from ECF as it was when that piece was shipped to ECF. As a result of these types of potential differences, these material balances should be considered as an indication that there is not a large potential deficit of fuel, and not an exact reconciliation.

All of the PWR-1 seed fuel was shipped to ECF from Shippingport. Attachment 2 provides a detailed listing of each shipment of seed fuel. The highly enriched uranium SOAP test assemblies are included in the seed fuel listing. This is summarized below. The "Element" refers to the total uranium mass while "Isotope" refers to U-235.

Table 1. Summary of PWR-1 Seed Fuel Received at NRF

Seed 1	32 Seed Assemblies Received	55,441 g Element (Total Uranium) 45,322 g Isotope (U-235)
Seed 2	32 Seed Assemblies Received	62,256 g Element 49,238 g Isotope
Seed 3	32 Seed Assemblies Received	63,630 g Element 47,440 g Isotope
Seed 4	32 Seed Assemblies Received	64,746 g Element 52,016 g Isotope
SOAP-I		760 g Element 477 g Isotope
SOAP-II		1,011 g Element 914 g Isotope
Total	128 Seed Assemblies Received & SOAP-I/SOAP-II Test Assemblies	247,844 g Element 195,407 g Isotope

Attachment 6 is a listing of the disposition of the PWR-1 seed fuel and SOAP test assemblies. Most of the shipments were to ICPP, which is consistent with the highly enriched uranium content of this fuel. Some SOAP fuel remains in storage at ECF today. A summary of Attachment 6 is provided below.

Table 2. Summary of PWR-1 Seed Fuel for Which Disposition is Known

Seed 1	52,988 g Element 43,304 g Isotope
Seed 2	60,801 g Element 48,087 g Isotope
Seed 3	61,891 g Element 46,143 g Isotope
Seed 4	64,734 g Element 52,015 g Isotope
Combined Seed or Unspecified Seed	4,781 g Element 3,744 g Isotope
SOAP	1,622 g Element 1,191 g Isotope
Total	246,817 g Element 194,484 g Isotope

The amount of seed fuel received slightly exceeds the amount listed in the known disposition table by 1.027 Kg total uranium with 0.923 Kg U-235. None of the records of known shipment of Shippingport fuel to RWMC included PWR-1 seed fuel or highly enriched uranium SOAP fuel. As discussed previously, the search for PWR-1 fuel reviewed several thousand transactions and a few individual transactions may have been overlooked during the search. Another possibility is that small pieces of PWR-1 seed fuel were included with other highly enriched uranium shipments to ICPP. There are records of shipments of small pieces of highly enriched fuel to ICPP for which the specific fuel type is not recorded. As noted above, the amount of uranium in any individual part of fuel may have changed due to different methods of estimating or calculating uranium content. Finally, it is likely that small amounts of PWR-1 seed fuel were destructively analyzed and the material became part of the other ECF radioactive waste streams that would have gone to RWMC. These other irradiated fuel material waste streams are evaluated in Section III.C. Due to the relatively small amount of PWR-1 seed fuel with unknown disposition, the lack of any disposal records clearly indicating disposal of PWR-1 seed fuel at RWMC, and the ready availability of a disposition path at ICPP in the 1960s for highly enriched uranium fuel, it is concluded that no separate RWMC source term is needed for PWR-1 seed fuel.

A separate material balance was performed for PWR-1 natural uranium blanket fuel. Attachment 3 lists the receipt of PWR-1 blanket fuel. This is summarized below.

Table 3. Summary of PWR-1 Blanket (Natural Uranium) Fuel Received at ECF

Total PWR-1 Blanket Fuel Received	4 Fuel Bundles 38 Blanket Assemblies 1 SABRE Assembly
Total (Mass) PWR-1 Blanket Fuel Received	4330 Kg U

Attachment 7 is a listing of the disposition of the PWR-1 blanket fuel. The search for sites where blanket fuel might have been sent was much more difficult than for the PWR-1 seed fuel because ICPP did not process natural uranium fuels and a much larger number of potential destination sites were possible. NRF performed a search of the fuel transaction records and the shipping manifests between 1960 and 1980 to identify any shipments that may contain PWR-1 blanket fuel. Most of the PWR-1 blanket fuel received at ECF was shipped to Hanford. Some blanket fuel remains in storage at ECF. Waste disposal records indicate that 214 Kg of natural uranium from PWR-1 were shipped to RWMC for disposal. A summary of Attachment 7 is provided below.

Table 4. Summary of PWR-1 Blanket Fuel for Which Disposition is Known

PWR-1 Blanket Fuel at RWMC	214 Kg U
PWR-1 Blanket Fuel Transferred to Other Sites	3811 Kg U
PWR-1 Blanket Fuel in Storage at ECF	304 Kg U
Total Accounted for PWR-1 Blanket Fuel	4329 Kg U

The amount of PWR-1 blanket fuel received exceeds the amount listed in the known disposition table by one Kg. This is a very small fraction of the amount of PWR-1 blanket fuel received at ECF. Minor differences in the quantity of PWR-1 blanket fuel shipped or in storage could be the result of various estimation methods, such as burn up calculations, assay sampling, fuel processing recovery amounts, etc. that could have been used to estimate the remaining fuel. Also, transfer records for natural uranium fuel were often rounded to the nearest kilogram which could account for small differences. Given the fact that the numbering and description of waste disposal records appears to be nearly complete and the amount of potentially unaccounted for blanket fuel is so small, this blanket fuel material balance does not constitute a data gap that would warrant assigning a higher value to the amount of PWR-1 blanket fuel disposed of at RWMC.

III.A.6 Calculation of Curie Content of PWR-1 Blanket Fuel Materials at RWMC

Attachment 8 provides an assessment of the curie content of the PWR-1 natural uranium blanket fuel materials sent to the RWMC. Various assumptions were used to provide an estimate of the curie content of the fuel materials. Attachment 8 defines assumptions made and the modeling used, and provides the results for radioisotopes of primary concern. The data in Attachment 8 provides isotopic activities per kilogram of uranium for a selected list of isotopes. These data along with the uncertainty discussed in the section below have been used to develop Table 5 which lists isotopic activities associated with the 214 Kg of natural uranium fuel materials shipped to the RWMC for disposal. (references g, m, q, r)

III.A.7 Uncertainty

Given that the results of the material balances correlate well with the review of burial records, the 214 Kg of natural uranium fuel materials at RWMC is considered accurate. As discussed in Attachment 8, the curie content per kilogram of natural uranium listed in Attachment 8 was calculated based on the average power of the blanket fuel. Since most of the blanket fuel bundles disposed of at RWMC were from locations that would be expected to have higher than average neutron flux levels, the best estimate of fission product radionuclides was obtained by multiplying the average power concentration from Attachment 8 by 1.5. An upper bound estimate for the fission product radionuclides is 50 percent above the best estimate, or a factor of 2.25 times the Attachment 8 concentration. For plutonium and other actinide radionuclides, the curie content calculation is approximately three times the values measured by actual chemical assays performed in the 1960s. Therefore, a best estimate for plutonium and other actinides is therefore obtained by first dividing by three to account for the known over calculation and then multiplying by 1.5 to account for the higher than average neutron flux

levels for the specific blanket bundle locations in the same manner as with fission product radionuclides. An upper bound estimate was obtained by multiplying by an additional factor of 1.5. The curie content for the uranium isotopes and their decay chain radionuclides has little uncertainty based on the expected accuracy of the 214 Kg of uranium sent to the RWMC. Therefore the best estimate and upper bound estimate are the same for uranium isotopes and their decay chains and are obtained without adjustment from the average power concentrations in Attachment 8.

III.A.8 Summary of Shippingport Evaluation

NRF reviewed shipping disposal manifests, fuel transaction records, monthly disposal records, etc. to evaluate the waste stream associated with fuel from the Shippingport Atomic Power Station. The review concluded that approximately 214 Kg of irradiated natural uranium materials associated with the Shippingport plant were disposed at the RWMC. Of the 214 Kg, approximately 5.5 Kg was in dissolved form absorbed in vermiculite. Approximately 190 Kg is likely to have intact cladding while 18 Kg should be considered to be in pellet form with potentially non-intact cladding. The total curie content for the best estimate and upper bound estimate for the dissolved and solid/pellet form of the fuel materials is shown in Table 5 below at one year of decay.

Table 5. Isotopic Activities for PWR-1 Irradiated Fuel Sent to RWMC (at One-year Decay)

<u>Isotope</u>	<u>Best Estimate Total Curies (Solid/Pellet)</u>	<u>Best Estimate Total Curies (Dissolved)</u>	<u>Upper Bound Total Curies (Solid/Pellet)</u>	<u>Upper Bound Total Curies (Dissolved)</u>
Ac-227	3.48E-08	9.19E-10	3.48E-08	9.19E-10
Am-241	1.08E+01	2.85E-01	1.62E+01	4.27E-01
Am-243	2.34E-02	6.16E-04	3.50E-02	9.24E-04
C-14	2.84E-02	7.49E-04	4.26E-02	1.12E-03
Cm-244	3.49E-01	9.21E-03	5.24E-01	1.38E-02
Cs-137	1.06E+04	2.80E+02	1.59E+04	4.20E+02
Eu-152	2.29E+00	6.04E-02	3.43E+00	9.06E-02
Eu-154	2.55E+02	6.73E+00	3.82E+02	1.01E+01
H-3	4.62E+01	1.22E+00	6.93E+01	1.83E+00
I-129	3.90E-03	1.03E-04	5.85E-03	1.55E-04
Nb-94	1.37E-05	3.62E-07	2.06E-05	5.43E-07
Np-237	2.66E-03	7.03E-05	3.99E-03	1.05E-04
Pa-231	4.84E-07	1.28E-08	4.84E-07	1.28E-08
Pb-210	3.44E-10	9.08E-12	3.44E-10	9.08E-12
Pu-238	1.18E+01	3.12E-01	1.77E+01	4.67E-01
Pu-239	4.43E+01	1.17E+00	6.65E+01	1.75E+00
Pu-240	3.86E+01	1.02E+00	5.79E+01	1.53E+00
Pu-241	3.03E+03	8.01E+01	4.55E+03	1.20E+02
Pu-242	2.55E-02	6.47E-04	3.83E-02	1.01E-03
Ra-226	5.19E-09	1.37E-10	5.19E-09	1.37E-10
Ra-228	4.38E-13	1.16E-14	4.38E-13	1.16E-14
Sr-90	6.24E+03	1.65E+02	9.36E+03	2.48E+02
Tc-99	1.49E+00	3.93E-02	2.24E+00	5.90E-02
Th-228	7.34E-05	1.94E-06	7.34E-05	1.94E-06
Th-229	1.26E-09	3.32E-11	1.26E-09	3.32E-11
Th-230	3.63E-06	9.57E-08	3.63E-06	9.57E-08
Th-232	1.95E-12	5.15E-14	1.95E-12	5.15E-14
U-232	1.58E-04	4.16E-06	1.58E-04	4.16E-06
U-233	1.44E-06	3.80E-08	1.44E-06	3.80E-08
U-234	5.80E-02	1.53E-03	5.80E-02	1.53E-03
U-235	9.43E-04	2.49E-05	9.43E-04	2.49E-05
U-236	1.00E-02	2.65E-04	1.00E-02	2.65E-04
U-238	6.84E-02	1.81E-03	6.84E-02	1.81E-03

III.B Evaluation of Disposition of Fuel Materials Associated with the First Two Cores of the S1W Prototype and USS NAUTILUS

III.B.1 Background on S1W Prototype and NAUTILUS

The design and construction of the S1W prototype occurred simultaneously as the design for the Mark II core (S1W-2), which was to be used in the first nuclear-powered submarine, USS NAUTILUS (SSN-571). Construction of NAUTILUS began on June 14, 1952. The power plant first operated on December 30, 1954 and reached full power on January 3, 1955. NAUTILUS set numerous speed, distance and submergence records for submarine operations that were not possible with conventional submarines. Among its many accomplishments was becoming the first ship to reach the North Pole. NAUTILUS operated until May 1979 after 2500 dives and 513,000 miles.

The first two cores for both the S1W prototype and NAUTILUS were operated in the 1950s. The first S1W prototype core (S1W-1) operated from March 1953 until September 1955. The second prototype core (S1W-3) operated between March 1956 and November 1957. The first NAUTILUS core (S1W-2) operated from December 1954 until February 1957. The second NAUTILUS core (S1W-3A) operated between April 1957 and May 1959. After each refueling the NAUTILUS cores were sent to NRF where the S1W prototype facility and ECF were located. A full description of operations associated with ECF is provided in reference (s). The fuel from the first two cores of the S1W prototype and NAUTILUS were examined, tested, and prepared for reprocessing at either a fuel handling facility located within the S1W plant or at ECF.

The fuel used in the first two cores for both the S1W prototype and NAUTILUS was highly enriched uranium. The S1W plant also operated with some removable fuel assemblies that were installed and removed throughout the lives of the two cores. The vast majority of the spent fuel associated with the cores, including the removable fuel assemblies, was ultimately sent to ICPP for reprocessing to recover valuable highly enriched uranium.

III.B.2 Scope of the Early S1W and NAUTILUS Fuel Evaluation

Examination of spent fuel at ECF can involve the testing of small pieces that are removed from the fuel. Some pieces may also undergo destructive evaluation, such as chemical dissolution and measurement of the amount of individual radionuclides in those pieces. In some cases, these examinations resulted in waste containing small amounts of irradiated fuel materials. Prior to 1970, some of these wastes were disposed of at the RWMC at INEEL in accordance with the radioactive waste requirements at that time.

In reference (a), the DOE-ID requested NR/IBO assistance in resolving issues associated with characterizing the waste inventory for the RWMC. Of particular interest was the irradiated fuel associated with the first two cores of the S1W prototype plant and NAUTILUS. DOE-ID requested that early operations at NRF be reviewed to determine whether irradiated fuel material from these cores might have been sent to RWMC prior to implementation of transuranic waste limits in 1970.

III.B.3 Difference Between Previous and Current Assessment

NR/IBO initially evaluated this waste stream in a March 2002 letter (reference (I)), however the limited time available for that preliminary review resulted in considerable uncertainty. The initial March 2002 review was limited to an effort to calculate how much uranium would be left in these four spent cores at the end of core life and then compare this amount to the amount of uranium reported to have been recovered at ICPP. The conclusion of the initial assessment, based on the limited information on hand, was that small portions of these cores (very roughly estimated at 4.67 kilograms) might have been disposed of at the RWMC.

There were several major uncertainties in the March 2002 preliminary evaluation. The biggest uncertainty was the reported amount of uranium recovered at ICPP. This information attributed the output of various ICPP processing campaigns to individual spent cores. In addition, it was uncertain whether uranium recovery information for one of these cores (S1W-3A) was available at all.

The approach taken in this current evaluation was to perform a very detailed search and evaluation of all fuel transfer records of this era in an attempt to definitively account for the disposition of all of the fuel from these four spent cores. This evaluation confirmed that the uranium recovery information from specific ICPP processing campaigns cannot reliably be used to account for all of the fuel from these early spent cores. For example, shipments of S1W-1 fuel to ICPP started in 1956 and continued up to as late as 1963. In any given calendar year in the late 1950s and 1960s fuel shipped to ICPP would have come from several different spent cores. Another flaw in the approach of comparing spent core uranium inventories to ICPP uranium recovery was that some of this spent fuel was sent to other laboratories for evaluation. Other laboratories that received some spent fuel specimens included Bettis Atomic Power Laboratory, Knolls Atomic Power Laboratory, Oak Ridge National Laboratory, Battelle Memorial Institute, Argonne National Laboratory, Brookhaven National Laboratory, and General Electric-Hanford. In addition, the actual amount of uranium recovered after process losses at ICPP might not match the amount of uranium listed in records of shipments to ICPP. The use of ECF accountability records provides a consistent basis for tracking this material.

III.B.4 Classification of Information on Early Naval Cores

Due to the military significance of Naval nuclear propulsion, much of the information specifically associated with the S1W prototype and NAUTILUS cores is classified and cannot be discussed in detail in publicly available documents. This report is presented in an unclassified manner. Classified enclosures to this report provide additional detailed information and references to other documents.

III.B.5 Availability of Records

The records reviewed in this evaluation consisted of several types of information. The most useful records were the records of receipt of nuclear fuel at NRF and the records of transfer of spent fuel from NRF to other organizations. For the two S1W prototype cores, S1W-1 and S1W-3, receipt records were available for the new unirradiated fuel received at NRF. For the two NAUTILUS spent cores, S1W-2 and S1W-3A, the receipt records were for irradiated spent fuel. Records were available for transfer of irradiated fuel from each of these four early spent cores to a variety of organizations. Several design reports were available to understand the construction of these early cores in terms of how many fuel assemblies were present in each core. This information was useful in determining whether all of the fuel assemblies for each spent core were accounted for in the fuel transfer records. Attachment 9 is a classified summary of the receipt and disposition of these four cores and includes references to the core layout as well as the listing of various types and identities of fuel assemblies in each core and includes a diagram of the S1W-1 core. Finally, several documents were available

which discussed how much residual uranium was present in the spent cores. The most important of these records was the overall bookkeeping record of the inventory of highly enriched uranium at NRF.

III.B.6 Disposition of S1W-1 Fuel

The first S1W prototype core (S1W-1) was initially retained at NRF after refueling. The fuel was prepared for inspection and reprocessing by removing the non-fuel structural components of the fuel assemblies in a water pool in the S1W building. In addition, smaller portions of the fuel to be examined for testing purposes were sent to a hot cell in the S1W building. Attachment 10 is a classified listing of all of the shipments of S1W-1 fuel. A detailed search of fuel transaction records associated with S1W-1 accounted for all of the U-235 in this spent core. The vast majority of the fuel went to ICPP for reprocessing. Other transactions showed small quantities sent to the Bettis Atomic Power Laboratory in Pittsburgh, Argonne National Laboratory-West, and General Electric in Richland, Washington. Some fuel pieces were tracked as having been shipped from NRF to Bettis, and then on to Battelle Columbus, back to NRF, and finally on to ICPP.

For the S1W-1 core, there were 53 different records of shipment of pieces of this core. Over 100 specifically identified line items were included in these transaction records. Over 20 of these line items were for pieces or samples containing less than 10 grams of U-235 with some as small as 2 grams.

All of the fuel assemblies in this core were accounted for in this review. That is, the number of specific numbered fuel assemblies in the shipment records matched the number that were in the core according to the design references. Due to the experimental function of the prototype fuel, many of the fuel assemblies had been disassembled (subdivided) into smaller pieces and samples. However, traceability of the major parts of each assembly was maintained. Furthermore, the total weight of U-235 in all of the shipping records is exactly the total amount listed in the accountability records as having been present in this core at end-of-life.

In addition, S1W-1 core included several removable fuel assemblies that were installed and removed at various times during its lifetime. Attachment 11 is a classified listing of the removable fuel assemblies, their beginning of life fuel loadings and the history of when they were installed and removed from the core. Attachment 12 is a classified listing of the disposition of the removable fuel assemblies. Transaction records accounted for all but 0.26 grams of U-235 being sent to ICPP or Bettis-Pittsburgh. There were 11 different records of shipments of pieces of the S1W-1 removable fuel assemblies. Approximately 40 specifically identified line items were included in the transaction records with one as small as 1.27 grams of U-235. The very minor difference in quantities between end-of-life values and the transaction records are attributed to rounding of numbers upon subdivision and shipment as well as the possible introduction of a very small amount of fuel material into NRF waste streams. The fuel material in these other waste streams is addressed in Section III.C.

III.B.7 Disposition of S1W-3 Fuel

The second S1W prototype core (S1W-3) was removed from the plant in November 1957 and transferred to the S1W water pit for disassembly, inspection, and disposition. In addition, smaller portions of the fuel to be examined for testing purposes were sent to a hot cell in the S1W building. Attachment 13 is a classified listing of S1W-3 fuel assemblies and their disposition. Most of the fuel went to ICPP for reprocessing with smaller quantities transferred to Knolls Atomic Power Laboratory and Bettis Atomic Power Laboratory in Pittsburgh. For the S1W-3 core, there were 32 different records of shipment of pieces of this core. Over 120 specifically identified line items were included in these transaction records with some as small as 3.01 grams of U-235.

The major portions of all of the fuel assemblies in this core were accounted for in this review, either as intact fuel assemblies or identifiable major pieces of specific fuel assemblies. For one fuel assembly, a small portion of it was not accounted for. The total weight of U-235 in all of the shipping records was 130 grams less than the total amount listed in the accountability records as having been present in this core. There are some unresolved discrepancies in a few of the transaction records for this core. For one transaction record of miscellaneous sample material, the amount of U-235 was revised from 137 grams to 40 grams without explanation. A similar revision reduced the U-235 amount in another transaction by 18.03 grams without explanation. No specific transaction record could be found for a portion of one fuel assembly. This discrepancy appears to be the cause of most of the 130 gram overall deficit. No records were found which indicated that specific pieces or parts of this core were disposed of at RWMC. However, as with the other cores, it is possible that a very small amount of S1W-3 fuel was destructively analyzed and the material became part of the other NRF radioactive waste streams that would have gone to RWMC.

During S1W-3 core lifetime, there were several removable fuel assemblies. Attachment 14 is a classified listing of these removable fuel assemblies, their beginning of life fuel loadings and the history of when they were installed and removed from the core. Attachment 15 is a classified listing of the disposition of the removable fuel assemblies. There were 15 different records of shipments of pieces of these removable fuel assemblies. The majority of the fuel was sent to ICPP for reprocessing with smaller quantities sent to Battelle Memorial Institute in Ohio and Bettis Atomic Power Laboratory. Approximately 20 specifically identified line items were included in the transaction records with one as small as 2.1 grams of U-235. A weight comparison between end-of-life values and the values listed in the disposition transaction records had to be calculated because no documented end-of-life residual uranium values were found for these removable fuel assemblies. NRF performed a calculation of depletion of these fuel assemblies, based upon beginning-of-life fuel values and the known power history that each fuel assembly experienced. Based upon this depletion, and a review of individual disposal records of each fuel assembly, all but 87 grams were accounted for as being sent for laboratory analysis or to ICPP for reprocessing. Each of the numbered removable fuel assemblies is specifically accounted for in the disposition transactions either as intact fuel assembly or the major part of the fuel assembly. Some of the relatively small difference in fuel values may be ascribed to differences in depletion calculations and possibly to incomplete records for some subdivided samples. Also, it is possible that a very small amount of this fuel was destructively analyzed and the material became part of the other NRF radioactive waste streams that would have gone to RWMC. In one specific case, 5 grams of irradiated enriched uranium in a 1962 accountability record was specifically identified as unrecoverable uranium from some uranium bearing thermocouples, one of which came from a removable fuel assembly. The radioactivity in these other waste streams, including the 5 grams specifically identified as coming from the removable fuel assembly, is addressed in Section III.C.

III.B.8 Disposition of S1W-2 Fuel

The first NAUTILUS core (S1W-2) was received at NRF in March 1957. Disassembly of the core for inspection, sampling and disposition occurred between April and July 1957. Again the fuel was prepared for reprocessing by removing the non-fuel structural components of the fuel assemblies in the water pit at S1W. Attachment 16 is a classified listing of S1W-2 fuel assemblies and their disposition. A detailed search of fuel transaction records accounted for the entire U-235 amount associated with S1W-2 with the majority of it going to ICPP for reprocessing. Smaller transfers were made to Oak Ridge National Laboratory, Argonne National Laboratory, and Brookhaven National Laboratory. For the S1W-2 core, there were 32 different records of shipment of pieces of this core. Over 50 specifically identified line items were included in these transaction records with some as small as 4 grams of U-235.

All of the fuel assemblies in this core were accounted for in this review, either as intact fuel assemblies or identifiable major pieces of specific fuel assemblies. That is, the number of specific numbered fuel assemblies in the shipment records matched the number in the core according to the design references. Furthermore, the total weight of U-235 in all of the shipping records was the same as the total amount listed in the accountability records. Despite the fact that the shipping records exactly matched the inventory records, it is possible that a very small amount of S1W-2 fuel was destructively analyzed and the material became part of the other NRF radioactive waste streams that would have gone to RWMC. The fuel material in these other waste streams is addressed in Section III.C.

III.B.9 Disposition of S1W-3A Fuel

The second NAUTILUS core (S1W-3A) was received at NRF in 1959. The fuel was prepared for reprocessing by removing the non-fuel structural components of the fuel assemblies at the ECF water pit. Attachment 17 is a classified listing of S1W-3A fuel assemblies and their disposition. A detailed search of fuel transaction records associated with S1W-3A accounted for almost all of the U-235 with the entire core going to ICPP for reprocessing. For the S1W-3A core, there were 31 different records of shipment of pieces of this core. Over 80 specifically identified line items were included in these transaction records. Nearly all of the S1W-3A fuel assemblies were shipped to ICPP as intact fuel assemblies. There were relatively few smaller pieces and no very small gram quantity samples in the S1W-3A shipments.

All of the fuel assemblies in this core were accounted for in this review, either as intact fuel assemblies or identifiable major pieces of specific fuel assemblies. That is, the number of specific numbered fuel assemblies in the shipment records matched the number in the core according to the design references. The total weight of U-235 in all of the shipping records was 1.4 grams less than the total amount listed in the accountability records as having been present in this core. Part of this difference may have come from rounding differences in the many transactions and samples used to disposition the core. Also, it is possible that a very small amount of S1W-3A fuel was destructively analyzed and the material became part of the other NRF and ECF radioactive waste streams that would have gone to RWMC. The fuel material in these other waste streams is addressed in Section III.C.

III.B.10 Review of Waste Disposal Records

In addition to the fuel transaction review discussed above, a review of radioactive waste disposal records and weekly facility operational reports was performed to determine if these records indicated fuel material was sent to the RWMC from the first two S1W prototype and NAUTILUS cores. A nearly complete set of radioactive waste disposal records were available for waste sent from NRF to the RWMC since the beginning of waste generating operations at NRF in 1953. The early waste disposal records were recorded on a Radioactive Shipment Monitoring Record form that provided a general description of the material, the originator of the waste, the destination of the material, the method of shipment, radiation readings and approval signatures. Later, disposal records were maintained on Radioactive Shipment Record forms, which included additional information such as curie estimates and radioisotopes of concern.

A review of the disposal records from 1953 through 1970 did not show any specific pieces or parts of S1W prototype or NAUTILUS fuel having been sent to the RWMC. Descriptions provided on the early disposal records were typically not very detailed. However as shown on later disposal records in the 1960s, unusual or unique disposals usually contained a specific description of the item on the record. Also, each disposal record related to the small amounts of irradiated fuel in subassemblies of Shippingport pressurized water reactor (PWR) Core 1 specifically included a description that included

PWR subassemblies. This review did not find any identifiable pieces or parts of the early S1W prototype or NAUTILUS cores that were disposed of at RWMC.

III.B.11 Uncertainty

One potential source of uncertainty in this evaluation is the accuracy of the calculation of the residual uranium (and thus the fission products and actinides) in the spent fuel assemblies. All of the accountability records found during this review used uniform residual uranium concentrations across the entire core. That is, the amount of depletion and remaining uranium was considered to be exactly the same for each fuel region. This is clearly an oversimplification as the fuel depletion would have varied in different regions of the core. Also, for the S1W-1 core, the amount of residual uranium recorded in the accountability records as being in the spent fuel is known to be too high. This is known because the number of fissions necessary to reduce the fuel uranium content down to the accountability record value is significantly less than the amount of fissions necessary to have generated the thermal energy the core is known to have generated. However, since the accountability records consistently assigned depletion values calculated in the manner discussed above, the assigned end-of-life (EOL) values can be compared directly to the fuel values associated with the disposal of the fuel material.

In addition, item identification of the individual fuel assemblies in the disposal path allows one to conclude that the major parts of all the fuel assemblies have been accounted for, either as intact fuel assemblies or identifiable major pieces of specific fuel assemblies. Collectively, the total amount of U-235 listed in the shipping records was only 219 grams less than the total amount of U-235 that was present in these cores according to the fuel accountability records. This difference is less than 0.5% of the amount of U-235 that was in these four spent cores.

III.B.12 Summary of S1W Prototype and NAUTILUS Fuel Evaluation

Based on the information gathered during the detailed evaluation of fuel transaction records and waste disposal records, it is concluded that no specific identifiable pieces and parts of these four early spent cores were disposed at RWMC. That is based on the fact that all of the fuel assemblies of each of these spent cores could be accounted for in the disposition records, either as intact fuel assemblies or identifiable major pieces of specific fuel assemblies. Collectively, the total amount of U-235 listed in the shipping records was only 219 grams less than the total amount of U-235 that was present in these cores according to the fuel accountability records. This difference is less than 0.5% of the amount of U-235 that was in these four spent cores. Some of this material may have been shipped to ICPP later without being specifically identified as coming from these cores. Since there were a very large number of transactions and fuel amounts in each transaction were typically rounded to the nearest whole gram, some of this difference may have been caused by rounding. Also, it is possible that a small amount of fuel from these cores was destructively analyzed and the material became part of the other NRF and ECF radioactive waste streams that would have gone to RWMC. Due to the relatively small difference between the shipping records and the inventory records, the lack of any disposal records clearly indicating disposal of S1W prototype or NAUTILUS fuel, and the ready availability of a disposition path at ICPP in the 1950s and 1960s for highly enriched uranium fuel, it is concluded that no separate RWMC source term is needed for these early Naval cores.

III.C Evaluation of Potential Disposal of Other Miscellaneous Irradiated Fuel Material at RWMC

III.C.1 Purpose of Miscellaneous Irradiated Fuel Material Evaluation

In reference (a), DOE-ID requested NR/IBO assistance in resolving issues associated with characterizing the waste inventory for the RWMC. In addition to the particular interest in potential disposal of irradiated fuel materials from Shippingport and early Naval cores, DOE-ID requested that other miscellaneous irradiated fuel materials be evaluated. A possible contributor to this waste stream would be specimens from the irradiations test program and miscellaneous fuel scrap waste generated from core examinations. This portion of the study evaluates the possibility that such irradiated Naval Reactors fuel material might have contributed to the RWMC waste inventory prior to the implementation of transuranic waste limits in 1970.

III.C.2 Availability and Review of Records

Transfer of reportable quantities of nuclear material is normally accompanied by accountability transaction forms. From the earliest days of the Naval Nuclear Propulsion Program to the present time, transaction documents are on file for shipments to and receipts from other facilities. An exception is disposal of nuclear material at the RWMC. Disposal of nuclear material at the RWMC did not require transaction forms (equivalent to the DOE/NRF Form 741 used today). However, accountability personnel were required to maintain a balance of all nuclear material, similar to a checking account. Some documents are available to substantiate approved shipments of nuclear material to the RWMC. These documents take the form of approval letters that authorize disposal of the material and waste disposal records for shipment of radioactive material to the RWMC.

A nearly complete set of radioactive waste disposal records was available for waste sent from NRF to the RWMC since the beginning of waste generating operations at NRF in 1953. The early waste disposal records were recorded on a Radioactive Shipment Monitoring Record form that provided a general description of the material, the originator of the waste, the destination of the material, the method of shipment, radiation readings and approval signatures. Later, disposal records were maintained on Radioactive Shipment Record forms, which included additional information such as curie estimates and radioisotopes of concern.

A review of the disposal records from 1953 through 1971 was conducted to determine what nuclear material NRF sent for disposal at the RWMC. The following four tables present the information found in this review. The tables group the material by the following categories:

- Irradiated Enriched Uranium (Potentially Dissolved or Finely Divided Form)
- Irradiated Enriched Uranium (Solid Form)
- Irradiated Natural Uranium
- Unirradiated Natural Uranium

Table 6. Irradiated Enriched Uranium (Potentially Dissolved or Finely Divided Form)

Date	Disposal #	Description	Container	Vol. (ft ³)	Wt. (lbs)	Radiation Levels ^(a)	Curies	Isotopes	Disposal Location	Comments/Source
9/16/60	136	Fission Products in Liquid Solution with sufficient vermiculite to absorb all liquid	55 Gal. Drum	10.8	NL	50 R/hr 2 R/hr	8.3	U ²³⁵ (.69 gms)	Trench #19	Waste shipment record
3/2/67	67EWDR42	2 each cation exchanger tanks containing negligible amounts of fuel from sawing and milling operations (not more than 24 grams U-235)	Cask	16	NL	2.8 R/hr 250 mr/hr	3,600	U ²³⁵ < 24 gms	Trench 45	Waste shipment record
5/16/67	67EWD112	Ion Exchanger and Fuel Chips	Cask	16	26,000	50 mr/hr 2 mr/hr	14	U ²³⁵ < 50 gms	Not Listed	Waste shipment record
8/31/67	67EWD196	Contaminated Cleanup material. One gallon can containing dissolved U ²³⁵ samples, can is filled with absorbent material, total quantity of liquid in can is less than 50 ml	Boxes	192	NL	20 mr/hr 5 mr/hr	0.02	U ²³⁵ (0.4 gm)	Trench #45	Waste shipment record
3/5/69	69EWDR58	Metal Can with liquid and solid enriched Uranium material in two 5 gallon cans	Cans	10 gal.	40	700 mr/hr 25 mr/hr	1.4	U ²³⁵ (0.03 gm)	Trench #49	Waste shipment record
6/12/70	70EWD188	3 Resin Columns (PIC) sealed full of H2O containing Zirc chips and 0.68 grams of U235 (Fissile eq.) of which 10% could be U235 containing Transuranic elements	Scrap Cask	16	300	5 mr/hr	3	U ²³⁵ (0.68 gm)	Trench 52	Waste shipment record
6/12/70	70EWD189	2 Resin columns and chip filter	Scrap Cask	16	300	25 mr/hr	3	U ²³⁵ (0.68 gm)	Trench 52	Waste shipment record
6/12/70	70EW186A	Liquid fuel solutions absorbed in fullers earth along with residual solid waste (may contain small amounts of transuranic elements)	Poly Bottle in 5 Gallon Bucket	3	NL	2 R/hr	0.4	U ²³⁵ (0.12 gm)	Trench 52	Waste shipment record. States dilute Hf and HNO3 solutions
8/24/70	70EW276A	3 Fission counters, Blend #1 Chem. Lab solution in fullers earth	Dumpster	NL	NL	0.3 mr/hr	2.95 x 10 ⁻⁶	U ²³⁵ (1.38 gm)	Trench 53	Waste shipment record
10/4/71	Note 1	Solutions from punches	Note 1	Note 1	Note 1	Note 1	Note 1	1 g U235	Note 1	Nuclear material transaction PZB-VSB-2

Note 1: This information is not provided in the nuclear material transaction record.

NL – Not listed on disposal record.

(a) – Radiation levels are generally on contact readings. Second number refers to reading at one meter.

Table 7. Irradiated Enriched Uranium (Solid Form)

Date	Disposal #	Description	Container	Vol. (ft ³)	Wt. (lbs)	Radiation Levels ^(a)	Curies	Isotopes	Disposal Location	Comments/ Source
2/9/60	Note 1	Fission Counter F-6	Note 1	Note 1	Note 1	Note 1	Note 1	1.62 g U235	Note 1	From accountability records. Item unaccounted for, possibly at burial ground. Also possible that this counter was sent to ICPP with other material as reclaimable scrap.
5/22/61	Note 1	Fission Counter #729	Note 1	Note 1	Note 1	Note 1	Note 1	.000003g U235 .0000035 Nat'l U	Note 1	Unaccounted for. Discussed in accountability records.
8/27/62	Note 1	3 Fast Acting Thermocouple Subassemblies	Note 1	Note 1	Note 1	Note 1	Note 1	5 g U235	Note 1	From accountability record
8/24/65	861	Resin impregnated D1G samples, irradiated core components	Cask	16	NL	1 R/hr 100 mr/hr	700	U235 (no quantity listed – negligible)	Trench #39	Waste shipment record
11/15/65	909	24 pieces of mounted poly met samples in a can, S5W, PWR, and A2W material	Cask	16	26,000	NL	NL	U235 (no quantity listed – negligible)	NL	Waste shipment record. Not on BBWI copies.
8/22/66	66AWD17A	Rags, Scrap metal, Poly, Blotting Paper and Wood. 3 Each unirradiated low level flux mapping probes + 2 U-Zr wires	Box	284	NL	0.3 mr/hr 0.08 mr/hr	0.0007	Co ⁶⁰ <0.1 gm SS material	Trench #41	Waste shipment record
8/22/66	66SWD44A	507 U-Zr wire segments (total S.S. 2.49 gm; U ²³⁵ 2.32 gm) Fission Counter 75208 and 26 (Total S.S. 1.83 gm; U ²³⁵ 1.71 gm)	Box	12	NL	30 mr/hr 0.5 mr/hr	0.015	Total SS (4.52 gm) U ²³⁵ (4.03 gm)	Trench #41	Waste shipment record
12/27/66	66EWD204	86 pieces of residue (7 gm of U ²³⁵) Approval NRF#435-16, plus assorted non fuel hardware from PWR and A2W Disposal Operations	Cask	16	26,000	150 mr/hr 2.5 mr/hr	400	U ²³⁵ (7 gms)	Trench #43	Waste shipment record
7/31/67	67EWD172	Misc. Hardware and end boxes form S5W-3H Disposal Effort. Also A1W Flux wire with 0.32 gm U ²³⁵	Cask	16	26,000	2.5 R/hr 200 mr/hr	38,000	U ²³⁵ (0.32 gm)	Trench #45	Waste shipment record
1/12/68	68AWDR01	26 U-Zr wires	NL	20	NL	1 mr/hr 0.06 mr/hr	0.002	U ²³⁵ (Negligible)	Trench #46	Waste shipment record
4/29/68	68EWD75	2 Culligan Tanks containing saw filings and mill shavings of U ²³⁵ (Scrap insert Stainless Steel #1)	Cask	16	26,000	5 mr/hr 1.5 mr/hr	60	U ²³⁵ (13.55 gm)	Trench #47	Waste shipment record

Note 1: This information is not provided in the nuclear material accountability record.

NL – Not listed on disposal record.

(a) – Radiation levels are generally on contact readings. Second number refers to reading at one meter.

Table 7. (continued)

Date	Disposal #	Description	Container	Vol. (ft ³)	Wt. (lbs)	Radiation Levels ^(a)	Curies	Isotopes	Disposal Location	Comments/ Source
8/27/68	68EWD158	23 each fuel specimens, S5W misc. hardware in insert #82	Cask	16	26,000	1 R/hr 50 mr/hr	1500 (total)	U ²³⁵ (total not listed)	Trench #48	Waste shipment record
9/27/68	68SWDR29	102 Flux wires U-Zr and 12 Fission counters Al-U235	Carton	12	30	150 mr/hr 10 mr/hr	0.15	U ²³⁵ (24.255 gms)	Trench #48	Waste shipment record
5/15/69	69EWDR93	Scrap cask contains metallic chips (less than .6 gm enriched U) and scrap hardware	Cask	16	24,500	250 mr/hr 15 mr/hr	53	U ²³⁵ < 0.6 gm	Trench #49	Waste shipment record
7/1/69 to 6/30/70	Note 1	Flux wires and samples	Note 1	Note 1	Note 1	Note 1	Note 1	36g U235 1g Np	Note 1	From PNR Survey, validating disposal
9/11/69	69EWDR210	1 gallon bucket with 24 plastic mounts with enriched U, Core Hardware in scrap cask	Cask	16	NL	NL	NL	U ²³⁵ (3.09 gm)	NL	Waste shipment record
9/22/69	69EWDR222	1 gallon bucket containing 25 small fuel specimens in scrap cask	Cask	16	26,000	NL	NL	U ²³⁵ (1.98 gm)	NL	Waste shipment record
11/20/69	69EWDR274	Misc. contaminated waste, i.e. rags, poly, blot paper, etc. Irradiated flux wires: Solid waste with 0.025 grams U-235 added to waste	Dumpster	204	NL	70 mr/hr 12 mr/hr	0.3	U ²³⁵ (0.025 gm)	Trench #51	Waste shipment record
12/11/69	69EWDR293	Misc. Hardware form S5W disposal effort also scrap TBR with 15 fuel pieces of Enriched U235 and 20 pieces of non-fuel. Insert #199	Cask	16	26,000	4 R/hr 350 mr/hr	4,500 (total)	U ²³⁵ (1.54 gm)	Trench #51	Waste shipment record
1/5/70	70EWDR03	S5W Hardware and 35 fuel specimens in scrap cask	Cask	16	500	NL	NL	U ²³⁵ (18 gm) Co ⁶⁰ , Zr ⁹⁵ , Nb ⁹⁵	NL	Waste shipment record
1/8/70	70EWDR02	S5W Hardware and Misc. Fuel chips in scrap cask	Cask	16	500	NL	NL	U ²³⁵ (6.36 gm) Co ⁶⁰ , Zr ⁹⁵ , Nb ⁹⁵	NL	Waste shipment record
3/19/70	70SWDR06	12 Nep. Foils, 12 U-235 foils, 12 Plut. Foils, 750 U-Zr wires, U-235 foil	NL	1	10	NL	NL	U ²³⁵ (2.0 gm) U ²³⁸ (60 gm) Pu ²³⁹ (1.2 gm) Np ²³⁷ (1.0 gm)	NL	Waste shipment record
4/27/71 Sent 5/3/71	E-94	U-235 solidified wastes containing Cs-137 and Ru-106.	55 gallon drum (3)	27	950	5 R/hr	0.918	U ²³⁵ (0.52 gm)	Pit 12	Waste shipment record. Also transaction PZB-VWB-1
6/24/71	Note 1	5 Fission Counters	Note 1	Note 1	Note 1	Note 1	Note 1	.39 g U235	Note 1	From accountability record

Note 1: This information is not provided with the nuclear material accountability record.

NL – Not listed on disposal record.

(a) – Radiation levels are generally on contact readings. Second number refers to reading at one meter.

Table 8. Irradiated Natural Uranium

Date	Disposal #	Description	Container	Vol. (ft ³)	Wt. (lbs)	Radiation Levels ^(a)	Curies	Isotopes	Disposal Location	Comments/ Source
7/14/67	67EWD166	Plutonium Shift Detector Plates and Sections (19 each) in a banded stainless steel box	Cask	16	125	700 mr/hr 15 mr/hr	48	U ²³⁸ (4.845 Kg) Pu (wt. Not listed)	Trench #45	Waste shipment record

Note: The Shippingport nuclear material is reported as a separate source term and is not included in this table.

(a) – Radiation levels are on contact and at one meter readings.

Table 9. Unirradiated Natural Uranium

Date	Disposal #	Description	Container	Vol. (ft ³)	Wt. (lbs)	Radiation Levels ^(a)	Curies	Isotopes	Disposal Location	Other
5/21/63	472	(2) unirradiated subassemblies (#1704B) (IRB-1), Zr solid pieces and Zr chips in can.	Lead Cask	13.5	NL	200 mr/hr	1000	Zr ⁹⁵ , Co ⁶⁰ U ²³⁸ (2.29 Kg)	Trench #30	Waste shipment record
10/9/63	543	One box 1' x 1' x 1' containing 109 PWR fuel rods	Dumpster	1	NL	5 mr/hr 0.1 mr/hr	0.005	U ²³⁸ (14.673 Kg)	Trench #33	Waste shipment record
2/11/64	599	One (BISA) subassembly wrapped in poly inside a metal container	NL	2	NL	NL	NL	U ²³⁸ (0.86 Kg)	NL	From accountability approval document
6/12/70	70EW186B	Unirradiated fuel specimens containing natural uranium (6 fuel specimens, 5 fuel rods, 1 bundle less 7 rods)	Wood box	3	50	NA	0.005	Normal U (16.07 Kg)	Trench 52	Waste shipment record

NL – Not listed on disposal record.

(a) – Radiation levels are generally on contact readings. Second number refers to reading at one meter.

These tables include information from the original documents that are not always clearly understandable or consistent. For example, terminology and acronyms were used that were not defined. In some cases, the record provided a range of uranium weights. In such cases the high end of the range was used in adding up the total uranium weight. Also, the curie content information is crude. Often a single number is assigned to the entire shipment without differentiating between the fuel related curies and other radioactive material in the same shipment. Thus, for the fuel radioactivity, the curie content has been separately calculated based on the total weight of irradiated uranium as discussed in Section III.C.3.

Several conclusions can be drawn from the information in the Tables 6-9. The total amount of enriched uranium listed in the tables is very small, 205 grams. For irradiated enriched uranium fuel materials, nearly all of the table entries were for forms other than identifiable fuel pieces or specimens. Common entries in the solid table included items such as wires, foils, fission counters, chips, absorbed solutions, samples, and punchings. The physical form of the material listed in these tables provides further evidence that larger pieces of Naval spent fuel were not disposed of at RWMC. This is consistent with the information from the material balance of the early Naval cores which indicated that numerous small pieces of fuel, some as small as 2 grams, were sent to ICPP for processing and uranium recovery.

For the purposes of environmental evaluation at RWMC, a conservative estimate is to assume that approximately 80 grams of the total 205 grams of irradiated enriched uranium may be in a dissolved or finely divided form. The remainder is in a solid form. Both the irradiated and unirradiated natural uranium listed in the above tables is in solid form with intact cladding.

III.C.3 Radioactivity Content

Bettis has calculated the radioactivity content of highly enriched uranium using the Oak Ridge National Laboratory computer code ORIGEN-S. For the enriched uranium calculation, 97.3% enriched uranium was conservatively assumed to be irradiated such that approximately 32% of the original U-235 remained. This depletion is typical of test reactor irradiations which test more extreme irradiation conditions. For the wide variety of irradiated uranium listed in the above tables, this amount of depletion would be conservative.

The following table lists the total curies (at one year of decay) as a best estimate and upper bound amount associated with the irradiated enriched uranium for the radionuclides of concern for the potentially dissolved or finely divided form and the solid form.

Table 10. Isotopic Activities for Irradiated Enriched Uranium Sent to RWMC

<u>Isotope</u>	<u>Best Estimate Total Curies (Solid)</u>	<u>Best Estimate Total Curies (Dissolved)</u>	<u>Upper Bound Total Curies (Solid)</u>	<u>Upper Bound Total Curies (Dissolved)</u>
Ac-227	2.38E-09	1.52E-09	4.28E-09	2.74E-09
Am-241	2.38E-03	1.52E-03	4.28E-03	2.74E-03
Am-243	5.10E-05	3.27E-05	9.19E-05	5.88E-05
C-14	2.36E-07	1.51E-07	4.25E-07	2.72E-07
Cm-244	4.10E-03	2.63E-03	7.39E-03	4.73E-03
Cs-137	2.07E+02	1.33E+02	3.73E+02	2.39E+02
Eu-152	1.05E-02	6.75E-03	1.90E-02	1.22E-02
Eu-154	1.15E+01	7.38E+00	2.07E+01	1.33E+01
H-3	8.17E-01	5.23E-01	1.47E+00	9.41E-01
I-129	4.94E-05	3.16E-05	8.89E-05	5.69E-05
Nb-94	8.59E-08	5.50E-08	1.55E-07	9.90E-08
Np-237	9.70E-04	6.20E-04	1.75E-03	1.12E-03
Pa-231	6.16E-08	3.94E-08	1.11E-07	7.09E-08
Pu-238	3.75E+00	2.40E+00	6.75E+00	4.32E+00
Pu-239	7.74E-03	4.96E-03	1.39E-02	8.93E-03
Pu-240	2.23E-03	1.42E-03	4.01E-03	2.56E-03
Pu-241	1.14E+00	7.30E-01	2.05E+00	1.31E+00
Pu-242	7.87E-06	5.03E-06	1.42E-05	9.06E-06
Sr-90	2.06E+02	1.32E+02	3.71E+02	2.38E+02
Tc-99	2.85E-02	1.83E-02	5.13E-02	3.29E-02
Th-228	9.45E-06	6.05E-06	1.70E-05	1.09E-05
Th-229	1.76E-10	1.13E-10	3.17E-10	2.03E-10
Th-230	1.49E-07	9.52E-08	2.68E-07	1.71E-07
U-232	3.39E-05	2.17E-05	4.07E-05	2.60E-05
U-233	4.27E-07	2.73E-07	5.12E-07	3.28E-07
U-234	7.01E-03	4.49E-03	8.41E-03	5.39E-03
U-235	8.60E-05	5.50E-05	1.03E-04	6.60E-05
U-236	8.78E-04	5.62E-04	1.05E-03	6.74E-04
U-238	3.75E-07	2.40E-07	4.50E-07	2.88E-07

The 4.845 Kg of irradiated natural uranium listed in Table 8 was irradiated in one of the NRF prototype reactors. The specific irradiation history of this material is not known. However, it would be reasonable to assume that its irradiation was similar to the Shippingport blanket fuel and scale its radioactivity content accordingly. Section III.A.8 of this report lists the calculated radioactivity content of 214 Kg (208.5 Kg solid form and 5.5 Kg dissolved form) of irradiated natural uranium in Shippingport blanket fuel. Multiplying the values in this table by 4.845/214 would provide a reasonable estimate of the radioactivity in this additional 4.845 Kg of irradiated natural uranium.

Table 11 provides the best estimate and upper bound estimate total curies associated with the irradiated natural uranium.

Table 11. Isotopic Activities for Irradiated Natural Uranium Sent to RWMC

<u>Isotope</u>	<u>Best Estimate Total Curies</u>	<u>Upper Bound Total Curies</u>
Ac-227	4.05E-10	6.07E-10
Am-241	2.51E-01	3.76E-01
Am-243	5.43E-04	8.14E-04
C-14	6.60E-04	9.90E-04
Cm-244	8.12E-03	1.22E-02
Cs-137	2.46E+02	3.69E+02
Eu-152	5.32E-02	7.98E-02
Eu-154	5.93E+00	8.90E+00
H-3	1.07E+00	1.61E+00
I-129	9.06E-05	1.36E-04
Nb-94	3.19E-07	4.79E-07
Np-237	6.19E-05	9.27E-05
Pa-231	5.62E-09	8.43E-09
Pb-210	1.20E-11	1.80E-11
Pu-238	2.75E-01	4.13E-01
Pu-239	1.03E+00	1.54E+00
Pu-240	8.98E-01	1.35E+00
Pu-241	7.05E+01	1.06E+02
Pu-242	5.94E-04	8.90E-04
Ra-226	1.21E-10	1.21E-10
Ra-228	1.02E-14	1.02E-14
Sr-90	1.45E+02	2.18E+02
Tc-99	3.46E-02	5.19E-02
Th-228	8.53E-07	1.28E-06
Th-229	1.46E-11	2.19E-11
Th-230	4.22E-08	6.32E-08
Th-232	2.27E-14	3.40E-14
U-232	3.66E-06	3.66E-06
U-233	3.35E-08	3.35E-08
U-234	1.35E-03	1.35E-03
U-235	2.20E-05	2.20E-05
U-236	2.33E-04	2.33E-04
U-238	1.59E-03	1.59E-03

The 33.893 Kg of unirradiated natural uranium listed in Table 9 would have the normal radionuclide content of natural uranium. This would include 1.13E-02 curies of U-238, 5.27E-04 curies of U-235, and 1.15E-02 curies of U-234.

III.C.4 Review of Policy Documents

An important part of the overall review of irradiated fuel material disposal at RWMC was to search for documents which discuss what the rules and policies were in the 1950s and 1960s. No documentation was found which indicated that disposal of irradiated fuel material was prohibited prior to the establishment of transuranic radionuclide limits in 1970. That is consistent with the observation that some burial records clearly indicated contents which included irradiated fuel material.

The disposal records show that the amount of irradiated natural uranium fuel materials disposed of at RWMC (214 Kg from Shippingport and 4.845 Kg from an NRF prototype plant) greatly exceeded the amount of irradiated enriched uranium fuel materials (205 grams). Furthermore, the Shippingport natural uranium was disposed of in subassembly bundles as large as 16 Kg each while the irradiated enriched uranium disposed of at RWMC consisted of very small items and finely divided or dissolved material.

Highly enriched uranium was a valuable resource in the 1950s and 1960s. ICPP was located on the INEEL and processed spent highly enriched uranium fuels to recover the U-235 from these fuels. ICPP provided a ready outlet for any unneeded irradiated highly enriched uranium at NRF. Irradiated natural uranium fuels had some residual value both in the plutonium that could be extracted by chemical processing and the residual partially depleted uranium. However, there was no processing capability at INEEL for irradiated natural uranium. There was capacity for natural uranium fuel processing at Hanford. That is why the majority of Shippingport natural uranium blanket fuel was shipped directly from Shippingport to Hanford and why, of the blanket fuel shipped to ECF for examination, the majority was shipped from ECF to Hanford after examination.

Four documents were found during this review which confirmed that the differing availability of processing capacity resulted in the different treatment of natural uranium and amounts of irradiated fuel disposed of by NRF at RWMC. As discussed in Attachment 3, Shippingport blanket fuel was received at NRF between 1960 and 1966. By 1966, most but not all of the inspection work was completed for this fuel. In a letter dated May 12, 1966 (reference t), Bettis Atomic Power Laboratory sent a recommendation to the Pittsburgh Naval Reactors Office. Bettis reviewed the status of Shippingport blanket fuel at NRF and recommended shipping most of this fuel to Hanford for processing. Some blanket fuel was recommended for retention as "library" material and some recommended for further examination. Bettis recommended that "All residue from fuel rods retained for Reactor Metallurgy examination be disposed of by burial at NRTS at a later date." Burial at the NRTS (National Reactor Testing Station, the former name of INEEL) referred to burial at RWMC. The Bettis letter went on to explain that the recommendation to dispose of fuel rod residue at RWMC was made because the reclamation value of the fuel would be less than the transportation and handling costs to ship the material to Hanford. This Bettis recommendation was approved by a letter from Naval Reactors Headquarters dated May 31, 1966 (reference u). The Naval Reactors letter specifically reiterated the Bettis proposal that "All residue from fuel rods retained at ECF for examination will be disposed of by burial at a later date" and approved the Bettis proposal. Consistent with this recommendation and approval, NRF shipped two large shipping containers with Shippingport blanket fuel to Hanford on June 22 and August 1, 1966.

These plans were confirmed in an exchange of letters between Bettis and Naval Reactors in 1967 (references v and w). Naval Reactors approved a Bettis recommendation concluding that further examination of many of the retained PWR fuel rods was not needed, and they could be disposed of by burial. Of the overall total of 214 Kg of Shippingport blanket fuel buried at RWMC, all but approximately 10 Kg was shipped in 1967 and 1968.

These Bettis and Naval Reactors letters confirm several aspects about the burial of irradiated fuel materials at RWMC. They confirm that irradiated natural uranium was treated differently than irradiated highly enriched uranium due to the lack of INEEL processing capacity and the expense of shipping irradiated natural uranium to Hanford. They also confirm that this specific approval for burial at RWMC was limited to what were considered small amounts of material.

No documents were found which specifically identified policy with regard to burial of highly enriched uranium at RWMC. Such policy can only be inferred from the documentation of what happened. That documentation shows many shipments of highly enriched fuel to ICPP in the 1950s and 1960s, including records of large numbers of small pieces including pieces as small as 2 grams. On the other hand, records of shipments of irradiated highly enriched uranium to RWMC totaled only 205

grams and were essentially all very small, finely divided, or dissolved material. When combined with the explicit economic argument made in favor of natural uranium burial, these facts imply a policy of burying highly enriched irradiated uranium only when it was too small to collect and place in a container for convenient transfer to ICPP.

Three additional documents were identified as part of this review which show how the possibility of disposing of highly enriched uranium fuel was treated at NRF. In a letter dated June 24, 1970 (reference (x)), NRF reported to the Naval Reactors Idaho Branch Office that two small pieces of Naval spent fuel with a residual enriched uranium content of approximately 0.5 gram each were not found in their assigned location and were thought to have been accidentally included in a cask of irradiated non-fuel scrap sent to RWMC in January or February 1970. NRF stated that arrangements were being made with RWMC to attempt to excavate the cask liners and retrieve this material. NRF reported the unsuccessful results of this retrieval attempt in a letter dated July 8, 1970 (reference (y)). One item noted by this letter was that the thin sheet metal liners broke open when retrieved by a clamshell bucket operated by crane. Over a year later in a letter dated July 12, 1971 (reference (z)), NRF reported that the two missing fuel pieces had been found in a different location in ECF. This reported loss and search at RWMC for these two small fuel pieces occurred prior to imposition of the transuranic waste limitations in 1970. This event provides further evidence that there was no routine policy to dispose of enriched uranium fuel pieces at RWMC.

The description of this unsuccessful retrieval attempt in 1970 also shows that the irradiated waste scrap cask liners used in the 1960s were not like the thicker steel liners used in more recent decades. All of the irradiated PWR blanket fuel disposed of in the 1960s in the scrap cask would have been in similar thin, crushable liners. This physical form could complicate any future attempt to investigate or potentially retrieve this or similar material.

III.C.5 Nuclear Accountability Material Balances

As discussed in earlier sections of this report, NRF retains extensive noncomputerized paper files of early nuclear material transfers to and from NRF. NRF has always performed the “balancing of the books” required by Atomic Energy Commission (and later DOE) regulations. As part of this review, a search was made for records which would demonstrate how such inventories were made and the potential amount of nuclear material which was unaccounted for (and perhaps disposed of at RWMC). Unfortunately, the reports of reconciling of nuclear material inventories from the 1950’s and 1960’s were typically destroyed after a set number of years in accordance with specific document retention schedules. In fact only one such report for this time period was found. This was a nuclear material accountability audit conducted by the Pittsburgh Naval Reactors Office covering the period from July 1, 1968 to June 30, 1969 (reference aa).

Even though this single audit report only covers a small portion of the time in question, it nonetheless sheds light on how closely fuel was accounted for. The report stated:

“Twenty-four (24) grams of enriched uranium, 41 Kgs. of depleted uranium and 214 grams of plutonium were discarded to the burial grounds during the period covered by this survey. The enriched material was in the form of irradiated samples, fission counters and residues from tests performed. The depleted uranium and plutonium were contained in spent fuel bundles from PWR and determined to be uneconomical for recovery. All discards are reviewed and approved by PNR prior to disposal.”

Several conclusions can be drawn from this section. All of the RWMC disposals mentioned in this section have been documented in other sections of this report. The very small amount and description of enriched uranium is consistent with the overall total of 205 grams and types of materials listed in Section III.C.2. Furthermore, the statement about PWR depleted uranium fuel being

“uneconomical for recovery” is consistent with the conclusions of Section III.C.4 of this report for why irradiated natural uranium fuel was treated differently from enriched uranium.

This report went on to state:

“Material Unaccounted For (MUF) – Three (3) grams of enriched uranium, 1 Kg. (isotope) of depleted uranium and 1 Kg. of thorium were reported as MUF during the survey period. This was due to internal rounding procedures for accountability records.”

The fact that the Material Unaccounted For was so small and the reported disposals correspond well with the other records found for RWMC disposal provides further evidence that there were not additional unknown fuel disposals at RWMC that would not have been identified as part of this current review.

III.C.6 Uncertainty

Uncertainty has been evaluated in two ways. The first way was an attempt to estimate the uncertainty in the 205 gram total for miscellaneous enriched irradiated uranium. Tables 6-9 include a compilation of all known disposal records and accountability records indicating disposed fuel material at RWMC other than that associated with Shippingport. It is possible that items containing less than the accounting system reportable quantity of nuclear material were disposed of, but not reported as nuclear material. Such reports would not be required by the procedures of the time or by today's standards. These quantities would be less than 0.5 grams of enriched material and 0.5 kilograms of natural or depleted uranium. To conservatively bound any such omissions, there is a 20 percent uncertainty factor associated with the nuclear material totals. In instances where the disposal records provided an interval of fuel values (e.g. “less than 24 grams”), NRF adopted the conservative maximum value (24 grams, in the example). In addition, the curie distribution is estimated to have an uncertainty of plus or minus 50%. These uncertainties were factored into the curie totals provided in Table 10. For the irradiated natural uranium sent to RWMC, as shown in Table 11, the uncertainty provided in Section III.A.7 is applicable for this waste stream as well.

From a broader perspective, NRF has attempted to evaluate the possibility that there may be some other category of irradiated fuel disposal at RWMC that has not been identified by any of the reviews. This uncertainty evaluation looked at the overall range of documentation found and evaluated in this review. The totality of the evidence indicates that it is highly unlikely that there is any significant amount of irradiated fuel material disposed of at RWMC that has not been identified in this review. This evidence includes the following:

1. For the Shippingport PWR Core 1 and the S1W Prototype and USS NAUTILUS cores for which material balances were performed, nearly all of the highly enriched fuel was accounted for.
2. For the Shippingport Core 1 blanket natural uranium fuel, explicit records were found documenting the disposal at RWMC of all of the fuel which was not sent somewhere else or retained at NRF. Specific letters were found proposing and approving the disposal of small amounts of this blanket fuel material at RWMC.
3. Nearly all of the known fuel material disposals at RWMC were at least mentioned in the NRF disposal records even though the level of detail in these records was limited. Clearly, there was no aversion to mentioning fuel material in these records.

4. The ready outlet for highly enriched fuels at ICPP removed any need to dispose of highly enriched fuel pieces at RWMC. The existence of numerous records of transfer of numerous very small pieces to ICPP demonstrates that it was easy and routine to ship such material to ICPP.

5. The Pittsburgh Naval Reactors Office nuclear material accountability audit from 1968 and 1969 showed how disposals at RWMC were accounted for and that unaccounted for nuclear materials were extremely small and due to rounding errors.

Due to the totality of this evidence, the conclusion of this report is that no additional uncertainty factor needs to be assigned for nuclear fuel material disposed of at RWMC.

IV. Investigation of Other NRF Waste Streams

Previous evaluations of NRF waste sent to the RWMC provided generic waste stream descriptions for NRF generated waste. These evaluations focused on providing rough estimates of the radioactivity content for the radionuclides that were the primary contributors. As additional assessment and modeling was performed for the RWMC, additional information has been requested to provide more detailed descriptions of various waste streams. Recently, of particular interest, were those waste streams that were considered potentially mobile (i.e., liquid, sludge, irradiated saw fines and chips) and those that may present a safety concern during investigation or remediation of the RWMC. This section addresses those waste streams.

IV.A. Evaluation of Liquid/Sludge/Resin Waste Stream

IV.A.1 Purpose of Evaluation

The purpose of this assessment is to evaluate the waste stream associated with liquid, sludge, and resin sent from NRF to the RWMC particularly those associated with the high radiation levels during the 1950s and 1960s. In reference (a), DOE-ID requested NR/IBO to provide an assessment of the liquid waste streams that had high radiation levels because of the potential mobility of the contaminants associated with the waste stream. The vast majority of the liquid, sludge, and resin was disposed to the RWMC between 1953 and 1971. By 1971, this waste stream was significantly reduced. Very little liquid waste required disposal at the RWMC and that requiring disposal was solidified. Sludge and decontamination solution wastes were much reduced with implementation of new water processing equipment at NRF. Resins were packaged in cast concrete drums which significantly reduced mobility concerns. Based on this information, an evaluation of waste streams containing liquid, sludge, or resin disposed to the RWMC between 1953 and 1971 is provided below. Sludge and resin wastes disposed of after 1971 are included in the routine waste assessment of Section IV.D since they would have similar radionuclide characteristics and represents a small fraction of that waste stream.

IV.A.2 Background of Liquid Radioactive Waste Generated at NRF

Various processes at NRF generated liquids, sludges, and resins that required disposal to the RWMC. Most of the liquid waste generated at NRF was disposed to leaching ponds and beds located at NRF. From 1953 to 1979 approximately 388,000,000 gallons of radioactive liquid containing 345 curies of radioactivity were estimated to have been sent to the NRF ponds and beds (reference (bb)). Some of the liquid wastes generated during early operations at NRF were sent to hold up tanks or evaporator systems where the precipitates or concentrates were collected for disposal to the burial ground. This

waste was not disposed to the NRF leaching ponds and beds because it would have reduced the leaching capacity of the ponds and beds. Other waste generated during early operations included spent resins and decontamination solutions. Some potentially contaminated oil from oil-water separators was also sent to the RWMC for disposal.

IV.A.3 Liquid Waste Disposal Methods

Liquid waste disposal to the RWMC required approvals prior to discharge. From information provided on the disposal records and weekly operational reports, the typical disposal method for the early NRF liquid/slurry shipments was to send the material to the RWMC in a tanker truck. North of the S1W prototype plant there was an area known as the Hot Waste Tanker loading area. The tanker was likely attached to the waste disposal piping from S1W and the contents pumped to the tanker truck. Once the liquid/slurry was transferred to the tanker truck (or possibly when certain radiation levels were obtained), the tanker was disengaged and sent directly to the burial ground. The tanker truck was also referred to as a portable sludge transfer tank and consisted of a steel tank on a trailer for transport to the burial ground. At ECF, the tank was filled by a flexible hose connected to an outlet on the west side of the ECF building and could be cleaned and flushed by a portable flushing unit. At the burial ground, it was likely that a hose was attached and the contents emptied into an excavated trench. The disposal records indicate that, in some instances, the tanker was flushed with fresh water. This was likely a standard practice for this type of waste. Disposal of the liquid/slurry in the tanker continued until 1964. Once disposal with the tanker was discontinued, absorbed or solidified slurry and sludge type shipments increased. The slurry and sludge was typically absorbed in vermiculite during the 1960s and was later solidified, placed in drums, often encased in concrete, and shipped to the RWMC.

Another liquid waste stream from NRF was the water that was shipped with zirconium chips to keep the chips wet and prevent potential combustion with oxygen in the air. From 1956 to mid-1962, the water was discharged with the chips. After 1962, the water was sent back to NRF and was not discharged. The water likely originated from the S1W or ECF water pools, which due to filtration systems in place, contained very low levels of radioactivity. Because of the expected low level of radioactivity associated with this water, it is not considered in this assessment.

Very early on, spent resin from NRF may have been discharged without containment into open trenches. However, disposal records indicated that, by 1958, the resin was sent in sealed disposable steel containers. The resins were associated with the prototype plants and ECF, and were used to remove impurities in various systems. After the resin was considered spent, it was removed from the plant or ECF and disposed to the RWMC as solid waste.

Absorbed decontamination solutions were disposed to the RWMC primarily in the 1960s. The solutions were used to clean plant components or systems. The typical decontamination solution was alkaline permanganate ammonium citrate (APAC). The solution was absorbed in vermiculite and sent to the burial ground in 55 gallon containers. Disposal of absorbed APAC occurred until 1971.

Another waste stream included potentially contaminated oil. This was primarily from the A1W prototype plant and was from an oil/water separator. The oil had very low levels of contamination, and the burial ground was the only disposal path available for the material. Up until 1965 the oil was collected in 55 gallon drums and disposed to the RWMC. Many of the disposal records indicated that the oil was absorbed in vermiculite. After 1965, a reusable tank was used that allowed the oil to be discharged directly into the trenches.

The waste streams discussed above represent the vast majority of waste sent to the RWMC that would be considered a mobile waste stream. There were individual disposals that included tanks taken out of service and one time liquid shipments. These disposals were very infrequent compared to the other disposals and likely possess the same radionuclide distribution.

IV.A.4 Volume Assessment of Liquid/Sludge/Resin Disposal

An initial assessment of the NRF waste streams that contained sludge, resin, and liquids in vermiculite was performed in 1994 (reference (cc)). At that time the focus of the assessment was to provide information on the volume of each waste stream and the total curies of the radionuclides that made up the majority of the waste shipment. The assessment estimated that 624 cubic meters were sent to the RWMC. This is equivalent to approximately 165,000 gallons. The estimate was obtained from information provided in the INEEL radioactive waste management information system (RWMIS), which relied on available disposal record information. Disposal records prior to 1960 may not have been available for this effort.

An attempt was made to verify the amounts provided in reference (cc). A review of the waste disposal records from 1953 through 1971 was performed. This represented the timeframe that most of the waste associated with the more mobile waste streams such as liquids, sludge, and resin was sent from NRF to the RWMC. A few disposals of solidified liquid occurred in the 1970s and 80s which would make the contaminants immobile compared to the earlier unsolidified disposals. Most of the liquid shipments occurred in the 1950s and early 1960s via the tanker truck. Approximately 75 shipments with a total of 160,000 gallons of water and slurry were sent to the RWMC in the 1950s and early 1960s. Reference (dd) provides a list of specific disposal records that were used to estimate the volume of liquid/sludge/resin type waste sent to the RWMC from NRF. The following table provides a yearly summary of the liquid/slurry, sludge, resin, APAC solutions, oil, and miscellaneous disposals from NRF to the burial ground.

Table 12. Summary of Liquid/Sludge/Resin Disposal by Year from NRF to RWMC

Year	Liquid/slurry* (gallons)	Sludge (ft ³)	Resin (ft ³)	APAC (gallons)	Oil (gallons)	Misc. (gallons)
1954	-	-	7.5	-	-	-
1955	-	-	26	-	-	-
1956	-	-	20	-	-	-
1957	47,100	20	32	-	-	-
1958	38,700	-	41	-	-	-
1959	25,600	-	42	-	-	-
1960	6,000	372	58	-	55	-
1961	8,000	109	177	-	110	1,250**
1962	10,200	132	-	110	220	-
1963	13,690	107	130	6,740	3,166	-
1964	12,000	233	40	4,908	385	-
1965	-	73	306	385	4,211	-
1966	-	1,252	-	5,154	2,763	-
1967	-	644	-	15	1,339	-
1968	-	137	47	-	2,631	-
1969	-	1,670	7	-	2,003	-
1970	-	445	315	-	450	-
1971	-	465	406	2,723	660	-
Totals	161,290	5,659	1,654	20,035	17,993	1,250

*This included disposals that were primarily liquid with some diatomaceous earth or slurry-type material.

**This was a one time shipment of 1,250 gallons of non-radioactive nitric acid to the RWMC acid pit.

Based on the information provided in the table above, the estimated volume of 624 cubic meters of solidified liquid/sludge/resin to have been disposed between 1955 and 1983 provided in reference (cc) is slightly underestimated. The amounts above total to approximately 960 cubic meters.

IV.A.5 Curie Content Assessment of Liquid/Sludge/Resin Disposal

Early disposal records showed that radiation readings from liquid and resin shipments were often very high (up to 50 Rem per hour (R/hr)). These readings were likely from the highest detected spot on the containers during shipping surveys and correspond to hot spots detected in the material. The radiation readings do not necessarily indicate longer-lived radionuclides in the material. For example a 25 millicurie hot spot of cobalt-60, which is a typical corrosion byproduct, would measure 50 R/hr on contact with the container.

Although early liquid disposal records show fission products associated with the waste stream, it is believed that listing fission products on the record was a standard practice for the time period. Most of the other types of waste sent from NRF to the RWMC during this timeframe also listed fission products as a constituent. The reason for listing fission products is not clear. It was not uncommon for the liquid shipments to include analysis results for strontium-90 and cesium-137 with statements that the liquid was well below drinking water standards.

The radioactivity in the liquid/sludge/resin waste stream is associated primarily with crud generated during normal plant operations. Crud primarily contains activated wear products from plant components that can enter the plant systems and collect in reactor core components. The crud can also be entrained into plant filter material and ion exchangers. The typical crud profile includes a

small amount of fission products and transuranic elements from tramp uranium impurities found in various metals.

The generic crud profile assumed a two week shutdown time which is the time from when the plant was shutdown until the waste was disposed to the RWMC. The two week shutdown was based on the frequency of shipments from NRF to the RWMC and the anticipated amount of time that was required to collect the waste and ship it to the RWMC. Two situations were modeled that would most closely represent early shipments of this type of waste. One was a tanker truck that was half-filled. This scenario was used since most of the large quantity shipments from NRF in the 1950s and early 1960s was in a tanker. The tanker used at NRF was shown on several disposal records as being 20 foot by 7 foot in size. This would represent a 5700 gallon tank. Most of the shipments that used the tanker showed the volume as being between 1500 and 3000 gallons. The tanker truck scenario represents the greatest volume of liquid sent to the RWMC. The other scenario considered was a 7 foot by 2 foot steel tank used to dispose of resin. This was an early reoccurring waste stream and disposal records provided radiation levels that could be used for curie estimates for these shipments.

The generic crud profile and radiation readings from the disposal records allowed an estimate of the curies per gallon for the liquid waste or curies per cubic foot for the resin/sludge waste. The curie amount per gallon is used to provide a total curie amount for the liquid/slurry, APAC solutions, and oil shipments. The curie amount per cubic foot is used to provide a total curie amount for the resin and sludge waste streams. The curie estimates are considered conservative (upper bound amounts) since generally the highest radiation readings observed in the shipping records were used for calculation purposes. A best estimate of curie totals would be 50 percent of the upper bound amounts. Tables 13 and 14 provide a summary of the total curie amounts for each radionuclide for these waste streams.

Carbon-14 (C-14) was not included in the generic crud profile, since it was evaluated as part of the 1998 assessment provided in reference (ee). The assessment concluded that 41 curies of C-14 was sent to the RWMC from NRF in waste streams other than activated metal associated with core structural material. Assuming the entire 41 curies was only from the liquid/sludge/resin waste streams, which is a very conservative assumption, and assuming the same ratio as the other radionuclides shown in the table below, an estimated 8.1 curies of C-14 would be from the liquid waste stream and an estimated 32.9 curies of C-14 would be from the sludge/resin waste stream.

Table 13. Isotopic Activities for the Liquid/APAC/Oil Waste Stream

<u>Isotope</u>	<u>Best Estimate Total Curies</u>	<u>Upper Bound Total Curies</u>
Co-60	5.05E+02	1.01E+03
Fe-55	1.01E+03	2.01E+03
Co-58	1.77E+03	3.53E+03
Cr-51	8.90E+01	1.78E+02
Fe-59	1.02E+02	2.04E+02
Zr-95	4.36E+01	8.71E+01
Nb-95	9.60E+01	1.92E+02
Mn-54	4.92E+01	9.83E+01
Ni-63	1.52E+02	3.04E+02
Ni-59	1.52E+00	3.04E+00
Sb-125	5.00E+00	1.00E+01
Te-125m	1.16E+00	2.31E+00
Nb-93m	7.60E+00	1.52E+01
Nb-94	1.02E-01	2.03E-01
Hf-181	4.03E+01	8.06E+01
Tc-99	5.05E-03	1.01E-02
Zn-65	2.44E+01	4.87E+01
Zr-93	1.01E-03	2.02E-03
Cs-134	1.00E-01	2.00E-01
Cs-137	2.03E-01	4.05E-01
Ba-137m	2.03E-01	4.05E-01
Kr-85	1.01E-02	2.02E-02
Sr-90	2.03E-01	4.05E-01
Y-90	2.03E-01	4.05E-01
I-129	2.03E-05	4.06E-05
Se-79	7.60E-07	1.52E-06
Sn-126	2.28E-06	4.56E-06
Th-232	4.82E-10	9.64E-10
U-232	7.60E-06	1.52E-05
Np-237	1.52E-08	3.04E-08
Pu-238	1.27E-03	2.53E-03
Pu-239	2.03E-04	4.06E-04
Pu-240	1.27E-04	2.53E-04
Pu-241	5.05E-02	1.01E-01
Pu-242	1.52E-06	3.04E-06
Am-241	1.78E-03	3.55E-03
Am-242m	1.02E-05	2.03E-05
Am-243	1.52E-05	3.04E-05
Cm-242	3.11E-02	6.21E-02
Cm-243	1.27E-05	2.53E-05
Cm-244	1.77E-03	3.54E-03
Cm-245	1.27E-07	2.54E-07
Ru-106	4.89E-01	9.78E-01
Ce-144	4.66E-01	9.31E-01
Pm-147	1.56E-01	3.11E-01
U-233	1.37E-06	2.74E-06
U-234	1.52E-06	3.04E-06
U-235	1.07E-10	2.13E-10
U-236	5.60E-09	1.12E-08
U-238	2.49E-08	4.97E-08

Table 14. Isotopic Activities for the Sludge/Resin Waste Stream

<u>Isotope</u>	<u>Best Estimate Total Curies</u>	<u>Upper Bound Total Curies</u>
Co-60	2.54E+03	5.08E+03
Fe-55	5.05E+03	1.01E+04
Co-58	8.90E+03	1.78E+04
Cr-51	4.50E+02	8.99E+02
Fe-59	5.15E+02	1.03E+03
Zr-95	2.20E+02	4.39E+02
Nb-95	4.83E+02	9.66E+02
Mn-54	2.48E+02	4.95E+02
Ni-63	7.65E+02	1.53E+03
Ni-59	7.65E+00	1.53E+01
Sb-125	2.53E+01	5.06E+01
Te-125m	5.80E+00	1.16E+01
Nb-93m	3.83E+01	7.65E+01
Nb-94	5.10E-01	1.02E+00
Hf-181	2.03E+02	4.06E+02
Tc-99	2.56E-02	5.11E-02
Zn-65	1.23E+02	2.45E+02
Zr-93	5.10E-03	1.02E-02
Cs-134	5.05E-01	1.01E+00
Cs-137	1.02E+00	2.04E+00
Ba-137m	1.02E+00	2.04E+00
Kr-85	5.10E-02	1.02E-01
Sr-90	1.02E+00	2.04E+00
Y-90	1.02E+00	2.04E+00
I-129	1.01E-04	2.04E-04
Se-79	3.84E-06	7.67E-06
Sn-126	1.15E-05	2.30E-05
Th-232	2.43E-09	4.85E-09
U-232	3.83E-05	7.66E-05
Np-237	7.65E-08	1.53E-07
Pu-238	6.40E-03	1.28E-02
Pu-239	1.02E-03	2.04E-03
Pu-240	6.40E-04	1.28E-03
Pu-241	2.55E-01	5.10E-01
Pu-242	7.65E-06	1.53E-05
Am-241	8.95E-03	1.79E-02
Am-242m	5.10E-05	1.02E-04
Am-243	7.65E-05	1.53E-04
Cm-242	1.57E-01	3.13E-01
Cm-243	6.40E-05	1.28E-04
Cm-244	8.95E-03	1.79E-02
Cm-245	6.40E-07	1.28E-06
Ru-106	2.47E+00	4.93E+00
Ce-144	2.35E+00	4.69E+00
Pm-147	7.85E-01	1.57E+00
U-233	6.90E-06	1.38E-05
U-234	7.70E-06	1.54E-05
U-235	5.35E-10	1.07E-09
U-236	2.81E-08	5.62E-08
U-238	1.25E-07	2.50E-07

IV.A.6 Uncertainty

The uncertainty associated with these waste streams is large (estimated at 100%); but that uncertainty is already factored into the conservative nature of the evaluation so that the curie amounts are considered upper bound estimates. The curie per gallon and curie per cubic foot were based on high radiation readings on shipments in the early 1950s and 1960s, which were identified as the primary shipments of concern. Later shipments did not show radiation readings as high as the early shipments. Plant chemistry improved through the years and would have resulted in less crud in plant systems and, more than likely, less radioactivity in most of these waste streams. Accordingly, the difference in best estimate and upper bound numbers in Tables 13 and 14 are based solely on the 100% uncertainty in the waste streams.

IV.A.7 Summary Liquid/Sludge/Resin Waste Stream

Determining the curie content and makeup of material sent to the RWMC for disposals as long ago as 40 to 50 years is difficult. The processes and operations have changed through the years. Most liquid disposal in the 1950s and 1960s went to NRF leaching beds and ponds. A much smaller amount went to the burial ground and was usually associated with slurry/sludge from plant systems. The liquid/sludge/resin type disposal from the 1950s and 60s primarily contained corrosion products or crud. Fission products and transuranic elements would not be expected in significant quantities. There is a large amount of uncertainty associated with the waste stream that drives the difference between best estimate and upper bound numbers in Tables 13 and 14. The calculated curie totals are considered upper bound estimates because the modeling assumed all liquid, sludge, and resin shipments have similar radiation levels and curie content, and the highest radiation readings were used for the scenarios considered. Liquid shipments with high radiation readings were discontinued in 1964. This appears to be the timeframe that free liquid discharges to open burial ground trenches were discontinued. Disposals after this time period were slurry or sludge that was absorbed in vermiculite or solidified. This would have reduced the migration potential of this waste stream. Resin disposals from at least 1958 and later were in sealed steel containers.

IV.B. Evaluation of Irradiated Saw Fines and Chips

IV.B.1 Purpose of Evaluation

The purpose of this assessment is to evaluate the irradiated saw fines and chips, commonly referred to as zirconium chips, waste stream sent from NRF to the RWMC. Reference (a) requested an evaluation of the more mobile waste streams associated with NRF waste sent to the RWMC and specifically identified irradiated metal fines as a potential mobile waste stream. The primary concern associated with this waste stream was the curie distribution particularly for activation products such as technetium-99, iodine-129, carbon-14, and chloride-36. Also of concern was the potential for significant chip oxidation as well as the possibility of groundwater dispersion and the combustible nature of finely divided zirconium. Finally, the disposal methods used to send it to the RWMC were assessed to determine their possible impact on dispersion through the environment.

IV.B.2 Background

Irradiated metal fines or zirconium chips are generated during the preparation of fuel assemblies for examination and long-term storage, and in the past, during the preparation of fuel for reprocessing. A saw or milling machine is used to partition the non-fuel material and, due to this operation, saw fines

and chips of zirconium and zirconium alloy (Zircaloy) are generated. NRF began milling operations in 1955 in the S1W water pool and hot cells. The first shipment of saw fines and chips to the RWMC was in early 1956. Sawing and milling operations were shifted to the Expanded Core Facility (ECF) in approximately 1958. Disposal of the zirconium chips to the RWMC occurred from 1955 through 1975 when it was discontinued.

IV.B.3 Disposal Method

Special handling methods were needed for the zirconium chips and fines because of the potential combustible nature of the waste. The handling and disposal methods varied through the years, but the primary objective remained the same; keep the zirconium chips wet to prevent combustion and to cover the material as soon as it was discharged into the burial ground trench to prevent them from drying out. At NRF, the chips were collected in a basket or bucket from the water pits and placed into lead shielded containers for transfer to the burial ground. During early operations in 1956 and 1957 these containers were small and were sometimes referred to as a "lead pig" on the disposal records. In 1958, larger containers referred to as a "trash cask", "chip carrier", or simply "cask" on the disposal records were used to transfer the chips. Because of the larger containers, chips were often sent to the burial ground with other core component debris. Disposal records in 1959 indicated that a disposable galvanized metal insert was placed inside the shielded cask, which was used to transfer the chips. Between 1956 and mid-1962, the chips were shipped with water, likely from the water pits, that was discharged into the RWMC trenches. The water prevented "spontaneous combustion", "zirconium fire", or "explosion hazard" as noted on early disposal records. Up until 1960, the disposal method was to discharge the chips with the water (usually between 100 to 300 gallons) into a trench, spread the chips out, and cover as soon as possible with three feet of soil. In late 1960, the disposal method changed in that the water was disposed at a location separate from the zirconium chips, however, the chips were still spread out and covered with three feet of soil.

Beginning in mid-1962, it became a standard practice to return the water to NRF after disposal of the chips. By this time, the zirconium chips were collected in five gallon square tin cans that were perforated at the bottom and loaded into a disposable cask inserts and transferred in a reusable shielded cask to the RWMC for burial. The shielded cask was filled with enough water to cover the zirconium chips during transport. At the burial ground the disposable insert was hoisted out of the water in the shielded cask, allowed to drain for a short period, placed in an open trench, and spread out by tipping the insert on its side. The material was covered with earth as soon as possible after discharge. These operations were performed with a boom crane and bulldozer. In 1965, disposal records specify covering the chips with six feet of soil instead of three feet.

Early in 1967, an assessment was made of the disposal method used for the zirconium chips (reference (ff)). During disposal operations, contamination was being spread to unintended areas due to wind or water splashing during removal of the cask insert. An improvement of the process was needed. The suggested disposal method was to keep the zirconium chips together in a small mass of less than 75 pounds, not spread it out like previously done, and to keep the material wet rather than moist or dry. To meet this suggested method, the chips were to be collected under water in a cylindrical five gallon container and would be sealed with lug-type fasteners to keep the chips covered in water. The containers were loaded into a disposable insert underwater and when the insert was raised out of the water, it would be drained. The zirconium chips, which remained in a closed five gallon container, would remain wet, but they could be handled and disposed of to the burial ground without excess water leakage or spread of contamination. Since the chips were in closed five gallon containers, the chips were disposed in scrap casks with other waste. Disposal of zirconium chips continued until 1975 when it was discontinued. Since 1975, zirconium chips have been stored in the ECF water pit.

IV.B.4 Volume Assessment of Zirconium Chip and Fines

An initial assessment of this waste stream was provided in reference (cc). At that time the focus of the assessment was to provide information on the amount (weight or volume) of each waste stream and the curie totals of the radionuclides that made up the majority of the waste shipment. That assessment estimated the amount of saw fines and chips disposed between 1955 and 1975 to be about 13,000 pounds. The estimate was obtained from information provided in the INEEL radioactive waste management information system (RWMIS), which relied on available disposal record information.

Estimating the weight of zirconium disposed to the RWMC from NRF is difficult since past disposal practices differed as stated above and the information contained on the disposal records varied through the years. During the early disposal period in 1956 and 1957, the zirconium chips appeared to be disposed of separately from other waste. This was more likely the result of small containers used for disposal rather than a concerted effort to keep the waste stream segregated. After 1957, the zirconium chips were often listed with other non-fuel structural material. This was probably the result of larger casks being available to ship larger quantities of debris. In mid-1965, it became apparent that the zirconium chips were once again shipped separately from other waste. At this time, additional information was included with the disposal records specifying the size of the chips and fines, and providing specific disposal directions. The zirconium chips were probably separated from the other waste streams because of their special disposal requirements, which included specifying disposal of the chips in an isolated section of the RWMC trench.

An attempt was made to verify the quantity of zirconium chips, 13,000 pounds, estimated to have been disposed to the RWMC as provided in reference (cc). Disposal records from 1966 and 1967 showed the weight of chips and fines sent to the RWMC as being approximately 3,500 pounds for each year for a total of about 7,000 pounds. This represents over half the estimated 13,000 pounds sent to the RWMC. The 1966 and 1967 amounts could be associated with a few years of higher shipping totals associated with specific projects at ECF such as the expansion of the water pits or operations requiring significant core structural cutting. A review of the data available for 1956 and 1957, which was the only other timeframe when the zirconium chips were separate from other waste streams permitting a simple estimation of weight, showed approximately 30 to 40 baskets or buckets of zirconium chips were sent to the RWMC. Assuming the baskets were five gallons in volume, which is similar to the volume of containers used in later years, each basket would weigh approximately 30 pounds when full, which was the approximate weight of the filled five gallon containers from 1966-67. Therefore, one would estimate about 1000 pounds were disposed for each year. Because of the large quantity of zirconium chips shipped in 1956-57 and 1966-67, they were probably associated with one-time efforts where significant milling and sawing operations occurred. Shipments of zirconium chips for other years do not appear to have the same quantity.

Shipments of zirconium chips from 1958 through mid-1965 were included with other core components scrap. It is assumed that when a basket or two of zirconium chips were filled, they were loaded in the casks with other scrap material. Between 1958 and mid-1965, forty shipments referenced zirconium chips or something similar in the material description. It is estimated that each shipment contained about two baskets of chips, which is similar to the amount sent with each shipment in 1956-57. Assuming two baskets with each shipment and assuming each basket weighed approximately 30 pounds would result in a total of 2,400 pounds of zirconium chips sent to the RWMC between 1958 and mid-1965. In late 1965, two shipments were made that appeared to contain only zirconium chips with a description similar to shipments in early 1966. Since the shipments in early 1966 each contained an estimated 445 pounds of zirconium chips, these two shipments in late 1965 would have approximately 900 pounds of chips.

After 1967, the quantity of chips sent to the RWMC appears to have dropped off significantly. Zirconium chips disposals after 1967 were again, on occasion, included with other structural material

waste. Estimating the amount attributable to zirconium chips based on the information provided on the disposal records after 1967 is not possible, because the records did not typically list the chips in the description of the material. In order to estimate the amount of chips sent from 1968 to 1975, process knowledge is used. After discontinuing shipments of chips in 1975, NRF collected the chips on site. From 1975 to 1986, it was estimated that 1500 pounds of chips were collected at NRF (reference (gg)). This would represent approximately 125 pounds per year. Assuming the process did not significantly change after 1975, this amount can be used as an estimate of the yearly total from 1968 to 1975. In addition, one disposal in 1970 specifically listed six cans, each with a five gallon capacity (total estimated weight of 150 pounds). Since it was specifically identified on the records, it was added to the estimated annual total for 1970. Reference (dd) provides a list of disposal records from 1956 to 1970 that specifically reference zirconium chips or other source documents (weekly operational reports) that referred to zirconium chip disposal. A summary of the amount of zirconium chips sent to the RWMC between 1955 and 1975 is summarized in Table 15. The table is based on disposal record information, weekly operational reports, and assumptions as discussed above.

Table 15. Zirconium Chip Disposal to RWMC

Year	Shipments	Weight
1956	25	1200
1957	15	900
1958	2	120
1959	5	300
1960	3	180
1961	8	480
1962	4	240
1963	8	480
1964	5	300
1965	7	1200
1966	9	3500
1967	14	3500
1968	Unknown	125
1969	Unknown	125
1970	Unknown	275
1971	Unknown	125
1972	Unknown	125
1973	Unknown	125
1974	Unknown	125
1975	Unknown	125
Totals	110	13,550

The 13,550 pounds shown in the above table closely corresponds with the estimated amount provided in reference (cc). Based on this assessment, the 13,550 pound estimate is considered accurate within plus or minus 50%, which is considerably less than the +100% and -80% estimated accuracy provided in reference (cc). Of the 13,550 pounds, it is estimated that 7%, or 900 pounds, is in the form of fines. The vast majority of the zirconium waste was in the form of larger chips. This information is based on disposal records from 1966-67 that indicated the estimated weight of both the fines and the chips. This would result in approximately 1000 pounds being attributable to fines and the remainder being attributable to chips. The 1966-67 disposal records indicate that the fines were no larger than 2 mils x 15 mils x 60 mils and the chips were no larger than 2 mils x 187 mils x 250 mils.

IV.B.5 Assessment of Corrosion Potential

The corrosion rate information for zirconium was provided in reference NR:IBO-98/034 letter dated February 27, 1998, "Additional Information on Past and Projected Future Radioisotope Inventory From the Naval Reactors Facility and Comments on the Assumptions Used in the Radioactive Waste Management Complex Performance Assessment" (reference (ee)). Zirconium, like stainless steel, immediately forms a protective, invisible oxide film on its surface upon exposure to air. This oxide film is composed of zirconia (ZrO_2) and is on the order of only 50 to 100 angstroms in thickness. This ultra-thin oxide prevents the reaction of the underlying zirconium metal with virtually any chemical reagent under ambient conditions. The only reagent that will attack zirconium metal at room temperature is hydrofluoric acid (HF). HF will dissolve the thin oxide layer off of the surface of the metal and thus allow HF to dissolve the metal itself, with the concurrent evolution of hydrogen gas. However, it would require a fairly concentrated solution of HF to cause this attack, which is not typically found in significant concentrations in natural water sources.

The size of the zirconium chips can be used to determine a surface area-to-volume ratio. Disposal records indicated that the maximum size of the fines were 2 mils by 15 mils by 60 mils and the maximum size of the chips was 2 mils x 187 mils x 250 mils. The fines were estimated in the disposal records to make up 7% of the total zirconium chip weight.

IV.B.6 Assessment of Curie Distribution and Uncertainty

A curie estimate was made using ORIGEN-S computer codes and typical neutron activation fluxes for the zircaloy structure. The radionuclides contributing the largest curie amounts at the time of disposal are typically those associated with relatively short half-lives (such as cobalt-60, zirconium-95, etc). Table 16 provides the curie amounts (best estimate and upper bound estimate) at a 6 month decay time for potential radioisotopes of concern associated with the zirconium chip waste stream based on an estimated weight of 13,550 pounds sent to the RWMC. The upper bound includes an uncertainty of 50 percent on the weight of material and an additional 50 percent on the curie estimate.

Table 16. Isotopic Activities for Zirconium Chips Sent to RWMC

<u>Isotope</u>	<u>Best Estimate Total Curies</u>	<u>Upper Bound Total Curies</u>
H-3	6.70E+00	1.51E+01
Ni-63	4.97E+00	1.12E+01
C-14	3.28E+00	7.38E+00
Cs-137	4.49E-01	1.01E+00
Pu-241	3.13E-01	7.04E-01
Sr-90	2.72E-01	6.12E-01
Ni-59	3.93E-02	8.84E-02
Pu-239	1.35E-02	3.04E-02
Eu-154	6.57E-03	1.48E-02
Cl-36	4.95E-03	1.11E-02
Pu-240	4.72E-03	1.06E-02
Nb-94	2.74E-03	6.17E-03
Pu-238	2.37E-03	5.33E-03
Am-241	1.78E-03	4.01E-03
Eu-152	6.06E-04	1.36E-03
U-232	1.67E-04	3.76E-04
Th-228	1.17E-04	2.63E-04
Tc-99	9.02E-05	2.03E-04
U-233	8.79E-05	1.98E-04
U-234	7.87E-06	1.77E-05
U-238	7.07E-06	1.59E-05
Cm-244	7.07E-06	1.59E-05
Pa-231	4.44E-06	9.99E-06
Np-237	1.16E-06	2.61E-06
Pu-242	9.77E-07	2.20E-06
Am-243	7.68E-07	1.73E-06
Ac-227	6.58E-07	1.48E-06
U-236	6.08E-07	1.37E-06
K-40	3.18E-07	7.16E-07
U-235	2.00E-07	4.50E-07
I-129	1.73E-07	3.89E-07
Th-232	1.33E-07	2.99E-07

IV.B.7 Summary

The assessment of the zirconium chip waste stream shows an estimated amount of 13,550 pounds of zirconium chips and fines were sent to the RWMC between 1956 and 1975. This estimate has a 50% uncertainty on both the curie estimate and the weight of material that is reflected in the difference between best estimate and upper bound numbers in Table 16. NRF has not sent chips or fines to the RWMC since 1975.

IV.C. Evaluation of Activated Structural Metal

IV.C.1 Purpose of Evaluation

One waste stream that has been generated at NRF and disposed of at the RWMC since the 1950s is activated structural metal which was removed from Naval spent fuel assemblies in preparation for examination and long-term storage, and in the past, during the preparation of fuel for reprocessing. The curie content of this waste stream was evaluated in detail most recently in 1997. As a follow up to request made in reference (a), additional information was requested for an evaluation of the radionuclide, Ci-36, that has not been evaluated before for this waste stream. Thus, as part of this evaluation, the 1997 calculations of the curie content of activated structural metal were reviewed to calculate Ci-36 as well as other potential nuclides of interest.

IV.C.2 Background

Activated structural metal pieces are removed during preparation of Naval spent fuel assemblies in preparation for examination and long-term storage, and in the past, during the preparation of fuel for reprocessing. These activated metal pieces do not contain fuel. Being close to the fuel assemblies in the reactor, these structural metal pieces are exposed to high neutron flux and thus become highly radioactive by neutron activation. Much of the radioactivity in these metal pieces comes from activation of the metals that make up the key constituents of the metal alloy. These radionuclides include nickel-63, nickel-59, and iron-55. Other radionuclides come from activation of elements which are present as trace impurities in the metals. These nuclides include cobalt-60 (from activation of trace cobalt), niobium-94 (from activation of trace niobium), and carbon-14 (from activation of trace nitrogen). In addition, trace impurities of uranium and thorium in metals result in production of small amounts of fission product radionuclides and transuranic radionuclides. The radioactivity in the activated structural metals is formed within the matrix of the metal itself. It can only be released when the surface of the metal is corroded. The activated metal waste stream has the largest number of curies of any of the NRF radioactive waste streams disposed of at the RWMC.

IV.C.3 Disposal Method

Due to the high radiation levels coming from the activated structural metal waste, these metal pieces have always been delivered to the RWMC in shielded casks. The metal pieces were loaded in a disposable liner that was discharged from the reusable shielded cask at RWMC. The liners used in the 1960's were relatively thin sheet metal liners that only provided sufficient structural strength to make the transfer to the burial location. These liners would not retain their shape under burial loads and would not provide any long term structural rigidity. Since the 1970s, the activated structural metal pieces have been disposed of in a thicker metal liner.

IV.C.4 Assessments of Curie Content

Consistent with other NRF radioactive waste streams in the 1950's and 1960s, methods used to calculate the curie content of the activated structural metal were inconsistent and inaccurate. Although a consistent method was in place from the mid-1970s to 1989, this method was based on an erroneous formula for converting radiation levels measured underwater at ECF to curie content. In 1989, this method was discovered to give erroneous results which were too low by a factor of up to 1000. In reference (hh), NRF provided recalculated curie contents for activated metal shipments from 1976 through 1989. The isotopes calculated in 1989 only included the major radionuclides such as

Co-60, Ni-63, Fe-55, Co-58, Sb-125, Zr-95, and Sn-119. In reference (ii), NRF provided information on the activated structural metal waste stream back to 1955.

In 1997, NR/IBO was requested to review this waste stream to determine the curie content of long-lived radionuclides of potential importance to the Performance Assessment of the RWMC. C-14 was of particular interest since it was thought to be limiting for the Performance Assessment. Other radionuclides specifically requested to be calculated were I-129, Tc-99, K-40, Sr-90, and Ni-59. The Bettis Atomic Power Laboratory near Pittsburgh, Pennsylvania performed this assessment since they had design cognizance for most of the Naval spent fuel types. The number of spent fuel cores and fuel assemblies of each core type was known with good certainty. Similarly, the metals used and their dimensions were also known with good certainty. Using this information and the neutron fluxes previously calculated for each core type, activation calculations were made. An effort was made in this 1997 review to gather all available information on key trace element contents of various structural alloys. Particular emphasis was placed on getting the best available information on trace nitrogen content in order to reduce excess conservatism in the calculation of C-14. Similar effort was made to collect all available information on niobium content for calculation of Nb-94. The results of this review were provided in reference (ee).

In 2001, NRF contracted with Argonne National Laboratory to measure the curie content of three actual pieces of irradiated structural material. This was done in order to obtain an indication of how actual results would compare with the calculated curie content. For the three items, the calculated curie content was higher than the measured amount by factors of approximately 3, 7, and 40. Thus, even though considerable effort was made in the 1997 calculations to remove excess conservatism, particularly in trace element content, considerable conservatism likely remains in the neutron flux levels calculated for the structural pieces.

As noted above, it was requested that chlorine-36 be calculated as part of this review. Previously, a Cl-36 source term has not been calculated for Naval waste streams. Cl-36 is formed from activation of naturally occurring Cl-35. Chlorine is generally considered to be a detrimental material in reactor coolant systems and reactor structural material, and considerable measures are taken to keep chlorine out of both metals and reactor coolant systems. Thus, chlorine has generally been assumed not to be present in Naval materials. In view of the recent request to specifically consider Cl-36, a review was performed of structural material specifications and actual past measurements of chlorine content in structural metals. While all of these past measurements have not indicated any measurable chlorine content in Naval materials, a calculation has been made for activated metals based on an assumed chlorine impurity of 1 part per million (ppm) in Naval structural materials. Using the same methods as the 1997 evaluation, Cl-36 was calculated for some types of materials and extrapolated for the rest of the activated metals sent to RWMC. The total estimated curie amount calculated for Cl-36 in activated metal is 0.41 curie. Due to the immeasurable amount of chlorine in reactor coolant and crud, the presence of Cl-36 in the more mobile liquid/waste/resin waste form would be negligible. Since no actual chlorine has been measured in Naval materials, the Cl-36 calculation for activated structural metals should be considered an upper bound estimate.

While Cl-36 was specifically requested to be calculated as part of this review, DOE-ID also requested that transuranic radionuclides, uranium isotopes, Co-60, and some additional fission products be calculated if feasible. These radionuclides were not specifically calculated in the 1997 effort. However, recent calculations of activated structural metals do include the full range of radionuclides. Thus, ratios of these additional radionuclides to Nb-94 were obtained from more recent calculations and applied to the 1997 Nb-94 historical total in order to obtain an estimate of these additional radionuclides. This extrapolation method has some additional uncertainty since the mixture of structural metals in the recent calculations would not exactly match the historical mixture. However, since the ratios Nb-94 to the other nuclides calculated in 1997 matched the ratios for these same nuclides in the more recent calculation within a factor of two, it is considered that using Nb-94 ratios to calculate the other radionuclides provides a reasonable result. For Co-60, this scaling method would

have produced an estimate of $6.2E+05$ curies. Since references (hh), (ii), and (jj) have estimated the Co-60 total to be $1.3E+06$ curies, this higher value was used for Co-60.

All of these values are considered upper bound estimates based on the previously reported assay of three actual pieces of structural waste which demonstrated substantial overestimation in the activation calculations.

IV.C.5 Uncertainty

As noted above, the 1997 curie contents were originally considered to be best estimate calculations. However, subsequent actual measurements of the curie content in three pieces of activated structural metal found that the calculated curie content was higher than the measured amount by factors of approximately 3, 7, and 40. Thus, the 1997 calculations substantially overstate the actual curie content. The relatively wide range of the over calculation factors indicates that there is still a substantial amount of uncertainty in these calculations.

Also, the 1997 calculations have not been updated to include the activated structural metals disposed of since 1997. This is considered to be a relatively small percentage of the total since the more highly activated scrap pieces have been retained in storage at ECF since the discovery of the curie calculation error in 1989. Given the demonstrated over conservatism of the 1997 calculations, these values should still be considered an upper bound estimate even with the additional material disposed of since 1997.

It is difficult to provide a true best estimate for this waste stream given that the over calculation for the three pieces ranged from 3 to 40. A reasonable best estimate would be half of the upper bound estimates in the following table.

IV.C.6 Curie Content Total

The total curies for the activated structural metal waste stream are provided in the following table.

Table 17. Isotopic Activities for Activated Metal Sent to RWMC

<u>Isotope</u>	<u>Best Estimate Total Curies</u>	<u>Upper Bound Total Curies</u>
Co-60	6.1E+05	1.2E+06
Ni-63	1.7E+05	3.4E+05
Ni-59	1.5E+03	2.9E+03
H-3	1.4E+02	2.7E+02
C-14	4.9E+01	9.8E+01
Pu-241	1.1E+01	2.2E+01
Cs-137	9.1E+00	1.8E+01
Sr-90	4.8E+00	9.6E+00
Nb-94	6.5E+00	1.3E+01
Pu-239	2.1E-01	4.2E-01
Cl-36	2.0E-01	4.1E-01
Am-241	1.4E-01	2.8E-01
Pu-240	1.3E-01	2.6E-01
Pu-238	8.9E-02	1.8E-01
Tc-99	2.6E-02	5.2E-02
U-238	1.5E-04	3.0E-04
U-234	1.4E-04	2.8E-04
I-129	4.9E-05	9.7E-05
U-236	1.3E-05	2.6E-05
U-235	4.0E-06	8.0E-06

IV.D Evaluation of Routine and Other Miscellaneous Waste

IV.D.1 Purpose of Evaluation

Since the 1950s, NRF has disposed of routine low level radioactive waste to the RWMC. The curie content of this waste stream was evaluated previously in references (ii) and (jj) and is summarized below.

IV.D.2 Background

Routine low level waste was generated as part of normal plant operations, maintenance, repair, and refueling associated with the NRF prototype plants and ECF. The majority of this waste included blotting paper, rubber gloves, rags, plastic bags, etc. with very low levels of radioactivity. In addition to this compactable and largely incinerable waste, there have also been occasional plant components that are not compactable and that contain higher quantities of radioactivity. Other routine waste included scrap wood and metal. Miscellaneous waste included bulk items such as concrete, empty tanks, contaminated soil, and, on limited occasion, items such as a reactor core barrel and spent radioactive sources.

IV.D.3 Disposal Method

Routine waste was typically packaged in poly bags and placed in cardboard or wooden boxes. In later years (after 1970), waste was sometimes compacted, if compatible, prior to disposal. The boxes were placed into trenches at the RWMC. Larger items were usually covered in plastic to prevent potential contamination spread prior to disposal.

IV.D.4 Assessment of Curie Content

This waste stream was evaluated in references (ii) and (jj) and published in references (cc) and (kk). The evaluation included reviewing past disposal records and databases that provided information on past disposals from NRF to the RWMC. Additional evaluation of this waste stream was not requested in reference (a) and is not included in this report. The estimates provided in the above references included only those radionuclides that contributed the largest percentages to the curie totals. Therefore, only Co-60, Ni-63, and Fe-55 were considered which are the primary radionuclides associated with routine waste generated at NRF.

Using the same ratio of radionuclides as shown in Section IV.A above, an estimate can be made for other radionuclides that may be present. In Section IV.A, the radionuclide distribution was based on a typical generic crud profile. Although this profile, has changed through the years as material technology has improved, it provides the best available conservative assumption of radionuclide distribution for the routine waste. The crud profile is based on a ratio to curies of Co-60. Although Ni-63 and Fe-55 are part of the crud profile, the curies provided in the above references for Ni-63 and Fe-55 are used instead of the crud profile ratio.

IV.D.5 Uncertainty

The previous assessments (references (ii) and (jj)) provided best estimate curie totals and have a high uncertainty. The uncertainty associated with the curie totals would be similar to that provided for the liquid/sludge/resin waste stream, which indicated an uncertainty of 100%. The upper bound estimate would therefore be twice the best estimate.

The best estimate and upper bound estimate of curies for the routine and miscellaneous waste stream are provided in Table 18.

Table 18. Isotopic Activities for Routine and Other Miscellaneous Waste Sent to RWMC

<u>Isotope</u>	<u>Best Estimate Total Curies</u>	<u>Upper Bound Total Curies</u>
Co-60	1.21E+05	2.42E+05
Co-58	4.23E+05	8.46E+05
Cr-51	2.18E+04	4.36E+04
Fe-59	2.42E+04	4.84E+04
Zr-95	1.04E+04	2.08E+04
Nb-95	2.30E+04	4.60E+04
Mn-54	1.17E+04	2.34E+04
Fe-55	5.97E+04	1.19E+05
Ni-63	1.93E+04	3.86E+04
Ni-59	3.63E+02	7.26E+02
Sb-125	1.20E+03	2.40E+03
Te-125m	2.78E+02	5.56E+02
Nb-93m	1.81E+03	3.62E+03
Nb-94	2.42E+01	4.84E+01
Hf-181	9.55E+03	1.91E+04
Tc-99	1.21E+00	2.42E+00
Zn-65	5.80E+03	1.16E+04
Zr-93	2.42E-01	4.84E-01
Cs-134	2.42E+01	4.84E+01
Cs-137	4.84E+01	9.68E+01
Ba-137m	4.84E+01	9.68E+01
Kr-85	2.42E+00	4.84E+00
Sr-90	4.84E+01	9.68E+01
Y-90	4.84E+01	9.68E+01
I-129	4.84E-03	9.68E-03
Se-79	1.81E-04	3.62E-04
Sn-126	5.44E-04	1.09E-03
Th-232	1.15E-07	2.30E-07
U-232	1.81E-03	3.62E-03
Np-237	3.63E-06	7.26E-06
Pu-238	3.02E-01	6.04E-01
Pu-239	4.84E-02	9.68E-02
Pu-240	3.02E-02	6.04E-02
Pu-241	1.21E+01	2.42E+01
Pu-242	3.63E-04	7.26E-04
Am-241	4.23E-01	8.46E-01
Am-242m	2.42E-03	4.84E-03
Am-243	3.63E-03	7.26E-03
Cm-242	7.38E+00	1.48E+01
Cm-243	3.02E-03	6.04E-03
Cm-244	4.23E-01	8.46E-01
Cm-245	3.02E-05	6.04E-05
Ru-106	1.16E+02	2.32E+02
Ce-144	1.11E+02	2.22E+02
Pm-147	3.75E+01	7.50E+01
U-233	3.27E-04	6.54E-04
U-234	3.63E-04	7.26E-04
U-235	2.54E-08	5.08E-08
U-236	1.33E-06	2.66E-06
U-238	5.93E-06	1.19E-05

V. Summary

The following tables provide best estimates and upper bound estimates for the specific radionuclides of concern identified by DOE that are associated with NRF waste streams. Table 19 provides the best estimate curie totals while Table 20 provides the estimated upper bound. These estimates are for the time of disposal and have not been decay corrected to the present time.

Table 19. Summary of Curies for Radionuclides of Concern Associated with NRF Waste Streams (Best Estimate)

Waste Stream	C-14 (in Curies)	Tc-99 (in Curies)	I-129 (in Curies)	Cs-137 (in Curies)	Sr-90 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	2.84E-02	1.49E+00	3.90E-03	1.06E+04	6.24E+03
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	7.49E-04	3.93E-02	1.03E-04	2.80E+02	1.65E+02
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	2.36E-07	2.85E-02	4.94E-05	2.07E+02	2.06E+02
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	1.51E-07	1.83E-02	3.16E-05	1.33E+02	1.32E+02
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	6.60E-04	3.46E-02	9.06E-05	2.46E+02	1.45E+02
Unirradiated Natural Uranium (1963-70)	--	--	--	--	--
Core Structural (1953-1997)	4.9E+01	2.6E-02	4.9E-05	9.1E+00	4.8E+00
Zirconium Chips (1953-75)	3.28E+00	9.02E-05	1.73E-07	4.49E-01	2.72E-01
Liquid/APAC/Oil (1953-71)	4.05E+00	5.05E-03	2.03E-05	2.03E-01	2.03E-01
Sludge/Resin (1953-71)	1.65E+01	2.56E-02	1.01E-04	1.02E+00	1.02E+00
Routine/Misc. (1960-93)	--	1.21E+00	4.84E-03	4.84E+01	4.84E+01
Total	7.28E+01	2.88E+00	9.19E-03	1.15E+04	6.94E+03

Table 19 (continued)

Waste Stream	U-233 (in Curies)	U-234 (in Curies)	U-235 (in Curies)	U-236 (in Curies)	U-238 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	1.44E-06	5.80E-02	9.43E-04	1.00E-02	6.84E-02
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	3.80E-08	1.53E-03	2.49E-05	2.65E-04	1.81E-03
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	4.27E-07	7.01E-03	8.60E-05	8.78E-04	3.75E-07
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	2.73E-07	4.49E-03	5.50E-05	5.62E-04	2.40E-07
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	3.35E-08	1.35E-03	2.20E-05	2.33E-04	1.59E-03
Unirradiated Natural Uranium (1963-70)	--	1.15E-02	5.27E-04	--	1.13E-02
Core Structural (1953-1997)	--	1.4E-04	4.0E-06	1.3E-05	1.5E-04
Zirconium Chips (1953-75)	8.79E-05	7.87E-06	2.00E-07	6.08E-07	7.07E-06
Liquid/APAC/Oil (1953-71)	1.37E-06	1.52E-06	1.07E-10	5.60E-09	2.49E-08
Sludge/Resin (1953-1971)	6.90E-06	7.70E-06	5.35E-10	2.81E-08	1.25E-07
Routine/Misc. (1960-93)	3.27E-04	3.63E-04	2.54E-08	1.33E-06	5.93E-06
Total	4.25E-04	8.44E-02	1.66E-03	1.20E-02	8.33E-02

Table 19 (continued)

Waste Stream	Np-237 (in Curies)	Pu-238 (in Curies)	Pu-239 (in Curies)	Pu-240 (in Curies)	Pu-241 (in Curies)	Am-241 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	2.66E-03	1.18E+01	4.43E+01	3.86E+01	3.03E+03	1.08E+1
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	7.03E-05	3.12E-01	1.17E+00	1.02E+00	8.01E+01	2.85E-01
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	9.70E-04	3.75E+00	7.74E-03	2.23E-03	1.14E+00	2.38E-03
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	6.20E-04	2.40E+00	4.96E-03	1.42E-03	7.30E-01	1.52E-03
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	6.19E-05	2.75E-01	1.03E+00	8.98E-01	7.05E+01	2.51E-01
Unirradiated Natural Uranium (1963-70)	--	--	--	--	--	--
Core Structural (1953-1997)	--	8.9E-02	2.1E-01	1.3E-01	1.1E+01	1.4E-01
Zirconium Chips (1953-75)	1.16E-06	2.37E-03	1.35E-02	4.72E-03	3.13E-01	1.78E-03
Liquid/APAC/Oil (1953-71)	1.52E-08	1.27E-03	2.03E-04	1.27E-04	5.05E-02	1.78E-03
Sludge/Resin (1953-1971)	7.65E-08	6.40E-03	1.02E-03	6.40E-04	2.55E-01	8.95E-03
Routine/Misc. (1960-93)	3.63E-06	3.02E-01	4.84E-02	3.02E-02	1.21E+01	4.23E-01
Total	4.39E-03	1.87E+01	4.68E+01	4.07E+01	3.21E+03	1.19E+01

Table 19 (continued)

Waste Stream	Co-60 (in Curies)	Ni-63 (in Curies)	Ni-59 (in Curies)	Nb-94 (in Curies)	Cl-36 (in Curies)	H-3 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	--	--	--	1.37E-05	--	4.62E+01
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	--	--	--	3.62E-07	--	1.22E+00
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	--	--	--	8.59E-8	--	8.17E-01
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	--	--	--	5.50E-08	--	5.23E-01
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	--	--	--	3.19E-07	--	1.07E+00
Unirradiated Natural Uranium (1963-70)	--	--	--	--	--	--
Core Structural (1953-1997)	6.1E+05	1.7E+05	1.5E+03	6.5E+00	2.03E-01	1.4E+02
Zirconium Chips (1953-75)	--	4.97E+00	3.93E-02	2.74E-03	4.95E-03	6.70E+00
Liquid/APAC/Oil (1953-71)	5.05E+02	1.52E+02	1.52E+00	1.02E-01	--	--
Sludge/Resin (1953-1971)	2.54E+03	7.65E+02	7.65E+00	5.10E-01	--	--
Routine/Misc. (1960-93)	1.21E+05	1.93E+04	3.63E+02	2.42E+01	--	--
Total	7.34E+05	1.90E+05	1.87E+03	3.13E+01	2.08E-01	1.97E+02

Table 20. Summary of Curies for Radionuclides of Concern Associated with NRF Waste Streams (Upper Bound)

Waste Stream	C-14 (in Curies)	Tc-99 (in Curies)	I-129 (in Curies)	Cs-137 (in Curies)	Sr-90 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	4.26E-02	2.24E+00	5.85E-03	1.59E+04	9.36E+03
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	1.12E-03	5.90E-02	1.55E-04	4.20E+02	2.48E+02
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	4.25E-07	5.13E-02	8.89E-05	3.73E+02	3.71E+02
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	2.72E-07	3.29E-02	5.69E-05	2.39E+02	2.38E+02
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	9.90E-04	5.19E-02	1.36E-04	3.69E+02	2.18E+02
Unirradiated Natural Uranium (1963-70)	--	--	--	--	--
Core Structural (1953-1997)	9.8E+01	5.2E-02	9.7E-05	1.8E+01	9.6E+00
Zirconium Chips (1953-75)	7.38E+00	2.03E-04	3.89E-07	1.01E+00	6.12E-01
Liquid/APAC/Oil (1953-71)	8.10E+00	1.01E-02	4.06E-05	4.05E-01	4.05E-01
Sludge/Resin (1953-1971)	3.29E+01	5.11E-02	2.04E-04	2.04E+00	2.04E+00
Routine/Misc. (1960-93)	--	2.42E+00	9.68E-03	9.68E+01	9.68E+01
Total	1.46E+02	4.97E+00	1.63E-02	1.74E+04	1.05E+04

Table 20 (continued)

Waste Stream	U-233 (in Curies)	U-234 (in Curies)	U-235 (in Curies)	U-236 (in Curies)	U-238 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	1.44E-06	5.80E-02	9.43E-04	1.00E-02	6.84E-02
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	3.80E-08	1.53E-03	2.49E-05	2.65E-04	1.81E-03
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	5.12E-07	8.41E-03	1.03E-04	1.05E-03	4.50E-07
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	3.28E-07	5.39E-03	6.60E-05	6.74E-04	2.88E-07
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	3.35E-08	1.35E-03	2.20E-05	2.33E-04	1.59E-03
Unirradiated Natural Uranium (1963-70)	--	1.15E-02	5.27E-04	--	1.13E-02
Core Structural (1953-1997)	--	2.8E-04	8.0E-06	2.6E-05	3.0E-04
Zirconium Chips (1953-75)	1.98E-04	1.77E-05	4.50E-07	1.37E-06	1.59E-05
Liquid/APAC/Oil (1953-71)	2.74E-06	3.04E-06	2.13E-10	1.12E-08	4.97E-08
Sludge/Resin (1953-1971)	1.38E-05	1.54E-05	1.07E-09	5.62E-08	2.50E-07
Routine/Misc. (1960-93)	6.54E-04	7.26E-04	5.08E-08	2.66E-06	1.19E-05
Total	8.71E-04	8.72E-02	1.69E-03	1.22E-02	8.34E-02

Table 20 (continued)

Waste Stream	Np-237 (in Curies)	Pu-238 (in Curies)	Pu-239 (in Curies)	Pu-240 (in Curies)	Pu-241 (in Curies)	Am-241 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	3.99E-03	1.77E+01	6.65E+01	5.79E+01	4.55E+03	1.62E+1
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	1.05E-04	4.67E-01	1.75E+00	1.53E+00	1.20E+02	4.27E-01
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	1.75E-03	6.75E+00	1.39E-02	4.01E-03	2.05E+00	4.28E-03
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	1.12E-03	4.32E+00	8.93E-03	2.56E-03	1.31E+00	2.74E-03
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	9.27E-05	4.13E-01	1.54E+00	1.35E+00	1.06E+02	3.76E-01
Unirradiated Natural Uranium (1963-70)	--	--	--	--	--	--
Core Structural (1953-1997)	--	1.8E-01	4.2E-01	2.6E-01	2.2E+01	2.8E-01
Zirconium Chips (1953-75)	2.61E-06	5.33E-03	3.04E-02	1.06E-02	7.04E-01	4.01E-03
Liquid/APAC/Oil (1953-71)	3.04E-08	2.53E-03	4.06E-04	2.53E-04	1.01E-01	3.55E-03
Sludge/Resin (1953-1971)	1.53E-07	1.28E-02	2.04E-03	1.28E-03	5.10E-01	1.79E-02
Routine/Misc. (1960-93)	7.26E-06	6.04E-01	9.68E-02	6.04E-02	2.42E+01	8.46E-01
Total	7.07E-03	3.05E+01	7.04E+01	6.11E+01	4.83E+03	1.82E+01

Table 20 (continued)

Waste Stream	Co-60 (in Curies)	Ni-63 (in Curies)	Ni-59 (in Curies)	Nb-94 (in Curies)	Cl-36 (in Curies)	H-3 (in Curies)
Shippingport Natural Uranium Fuel Material (Solid) (1960-68)	--	--	--	2.06E-05	--	6.93E+01
Shippingport Natural Uranium Fuel Material (Dissolved) (1960-68)	--	--	--	5.43E-07	--	1.83E+00
Miscellaneous Enriched Fuel Material (Solid) (1953-71)	--	--	--	1.55E-07	--	1.47E+00
Miscellaneous Enriched Fuel Material (Dissolved) (1953-71)	--	--	--	9.90E-08	--	9.41E-01
Miscellaneous Natural Uranium Fuel Material (Solid) (1953-71)	--	--	--	4.79E-07	--	1.61E+00
Unirradiated Natural Uranium (1963-70)	--	--	--	--	--	--
Core Structural (1953-1997)	1.2E+06	3.4E+05	2.9E+03	1.3E+01	4.05E-01	2.7E+02
Zirconium Chips (1953-75)	--	1.12E+01	8.84E-02	6.17E-03	1.11E-02	1.51E+01
Liquid/APAC/Oil (1953-71)	1.01E+03	3.04E+02	3.04E+00	2.03E-01	--	--
Sludge/Resin (1953-1971)	5.08E+03	1.53E+03	1.53E+01	1.02E+00	--	--
Routine/Misc. (1960-93)	2.42E+05	3.86E+04	7.26E+02	4.84E+01	--	--
Total	1.45E+6	3.80E+05	3.64E+03	6.26E+01	4.16E-01	3.60E+02

VI. References

- a) DOE Memorandum dated December 19, 2002, Review of Draft Report (EM-ER-02-213)
- b) DOE Memorandum dated March 11, 2004, Subsurface Disposal Area (SDA) Inventory (EM-ER-04-053)
- c) DOE Memorandum dated April 20, 2004, Request for Support (EM-ER-04-086)
- d) (DOE Memorandum dated July 14, 2004, Request for Support (EM-ER-04-152)
- e) WAPD-T-3007, The Shippingport Pressurized Water Reactor and Light Water Breeder Reactor, October 1993
- f) WAPD-320, PWR Core 1 Component Examination Program Summary Report, October 1969
- g) WAPD-T-1608, Isotopic Composition of PWR Core 1 Blanket Irradiated to 16,000 MWD/Metric Ton U: Theory Vs Experiment, September 1963
- h) WAPD-OP(PWR)RD-343, PWR Core 1 Seeds 1-5 Total Residual Seed Fuel Analysis, November 1966
- i) WAPD-296, PWR Core 2 Reactor Design Description Report, March 1968
- j) WAPD-PWR-TE-206, Shippingport PWR Core 2 Seed 1 Physics Test Results from Mid-life to End-of-Life Test Evaluation, March 1970
- k) WAPD-TM-1412 Addendum, Corrosion and Hydriding Performance Evaluation of 3 Zircaloy-2 Clad Fuel Assemblies after Continuous Exposure in PWR Core 1 and 2 at Shippingport, PA, December 1983
- l) NR:IBO-02/032 letter dated March 6, 2002, Follow-on Comments Regarding Naval Reactors Program Radionuclide Inventories at the Subsurface Disposal Area
- m) WAPD-TM-265, Isotopic Analysis of Irradiated Natural Uranium Dioxide Fuel Rods from PWR Core 1, February 1962
- n) WAPD-TM-637, Depletion Analysis of Shippingport (PWR) Core-1, Seeds 1 and 2, Using the TNT02 Computer Program, November 1967
- o) WAPD-MT(FZCT)-78, Disposal of MELBA Bundles, February 1981
- p) WAPD-OP(PWR)RD-608, PWR Core 1 Seeds 1, 2, and 3 Seed Fuel Punching Analysis, April 1968
- q) WAPD-PWR-RD-1557, PWR-1 Component Examination Program, May 1963
- r) WAPD-T-2004, Residual Fuel Content of Shippingport Core 1 Seed Fuel: Calculation Versus Experiment, June 1967
- s) Department of Energy Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact State; Volume 1, Appendix D, Attachment B; April 1995

- t) WAPD-CL(AM)-349 letter dated May 12, 1966, Disposal of Irradiated PWR Core 1 Blanket Fuel Bundles
- u) NR:RM:JKOkeson – S#394 letter dated May 31, 1966, PWR Core 1 Blanket – Disposal of Expended Fuel; Approval with Comment
- v) WAPD-OP(ICE)-480 letter dated June 15, 1967, Review of Potential Reductions in Expended Core Examination Work (Classified)
- w) NR:RM:JKOkeson – S#1039 letter dated August 15, 1967, Expended Core Examinations – Reductions in Scope of Selected Examination Programs; Approval of (Classified)
- x) WAPD-NRFE-4600 letter dated June 24, 1970 (Classified)
- y) WAPD-NRFE-4610 letter dated July 8, 1970, Fuel Pieces M-565 and M-566
- z) WAPD-NRFE-4839 letter dated July 12, 1971, Fuel Pieces M-565 and M-566
- aa) PNR Survey No. 43 (PZB No.11), Report of Survey of Inventory Management and Safeguards Control of Nuclear Material at the Westinghouse Electric Corporation Naval Reactors Facility for the Period July 1, 1968 to June 30, 1969 (Classified)
- bb) NRF Comprehensive Remedial Investigation and Feasibility Study, September 1997
- cc) INEL-95/0310, A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952-1983, Volume 2, Revision 1, August 1995
- dd) NRFEA-1241 letter dated February 27, 2004, Summary of Disposal Records of Mobile Waste Streams and Irradiated Metal Fines Sent from NRF to the Radioactive Waste Management Complex
- ee) NR:IBO-98/034 letter dated February 27, 1998, Additional Information on Past and Projected Future Radioisotope Inventory From the Naval Reactors Facility and Comments on the Assumptions Used in the Radioactive Waste Management Complex Performance Assessment
- ff) WAPD-NRFTS-RC-1122 dated February 1, 1967, Irradiated Zirconium Scrap Disposal
- gg) NRFE-E-930 dated March 4, 1987, Review of Disposal Evaluation for Radioactive Zircaloy Chips at Expended Core Facility (ECF)
- hh) NRFE-E-1448 dated February 27, 1989, Curie Content Estimates for ECF Scrap Casks
- ii) NRFEM-RR-1122 dated March 29, 1994, NRF Comments to the Radioactive Waste Management Complex (RWMC) Waste Inventory Report
- jj) NRFEM-ER-1223 dated July 11, 1994, Evaluation of NRF Radiological Waste Streams for Waste sent to RWMC from NRF (1984-1993)
- kk) INEL-95/0135, A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1984-2003, Volume 2, May 1995

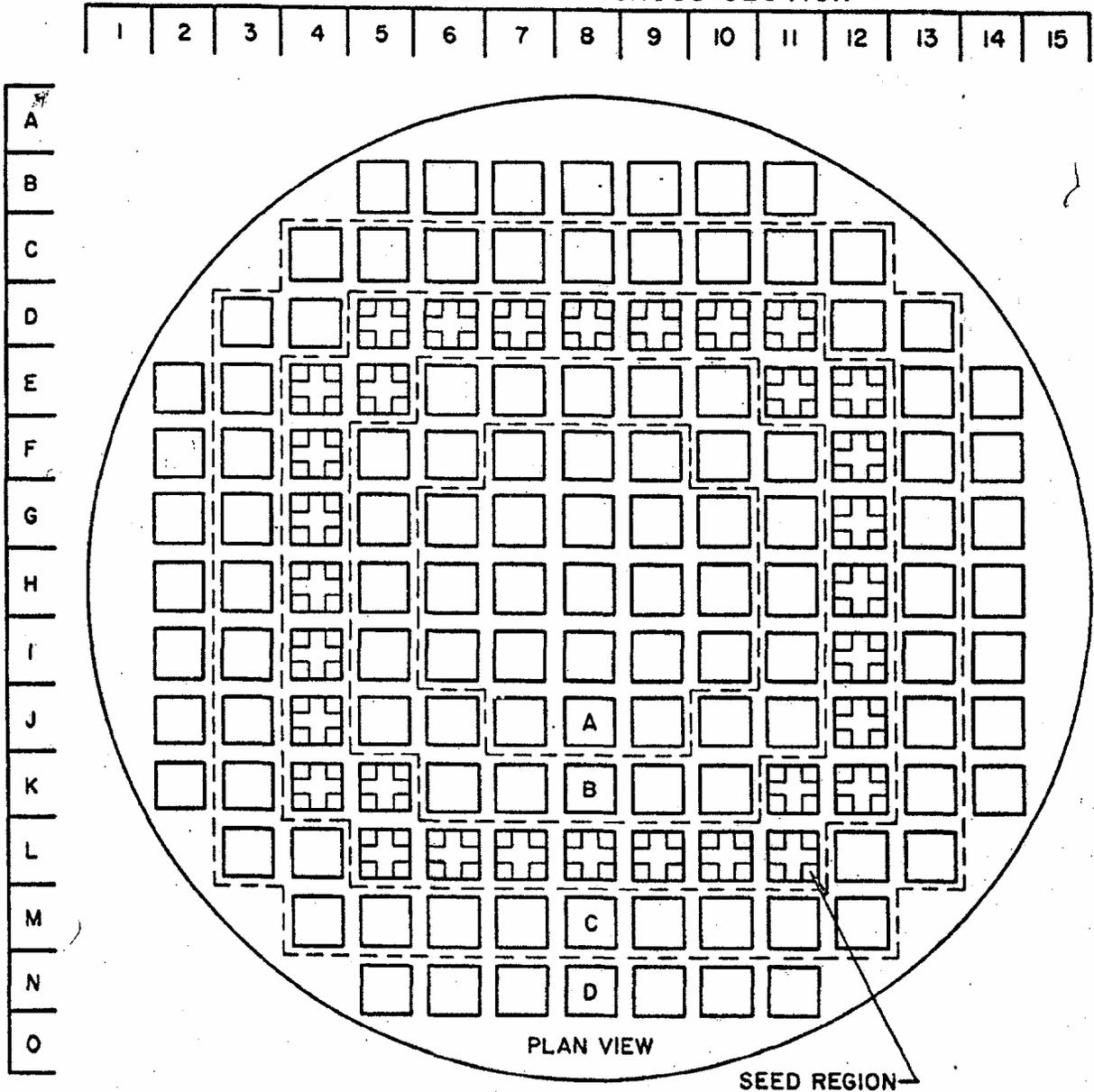
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Attachment 1

Shippingport PWR-1 Figures

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PWR - 1
SCHEMATIC CORE CROSS SECTION



- LEGEND**
- A — BLANKET REGION NO. 1
 - B — BLANKET REGION NO. 2
 - C — BLANKET REGION NO. 3
 - D — BLANKET REGION NO. 4

Figure 1. Cross-Section of Shippingport PWR-1 Core

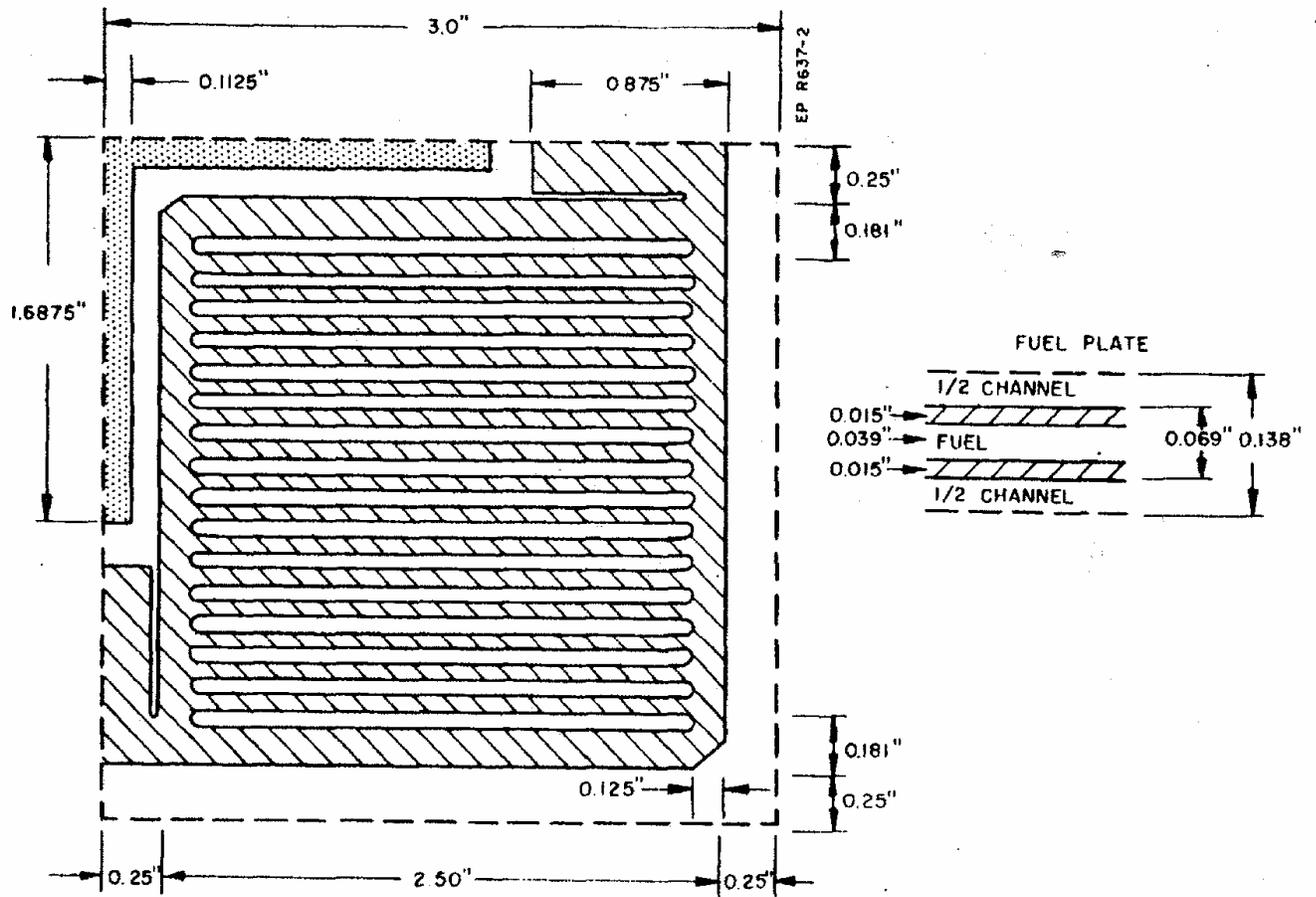


Figure 2. Cross-Section of PWR-1 Seed Subassembly
 NOTE: DIMENSIONS ARE IN INCHES

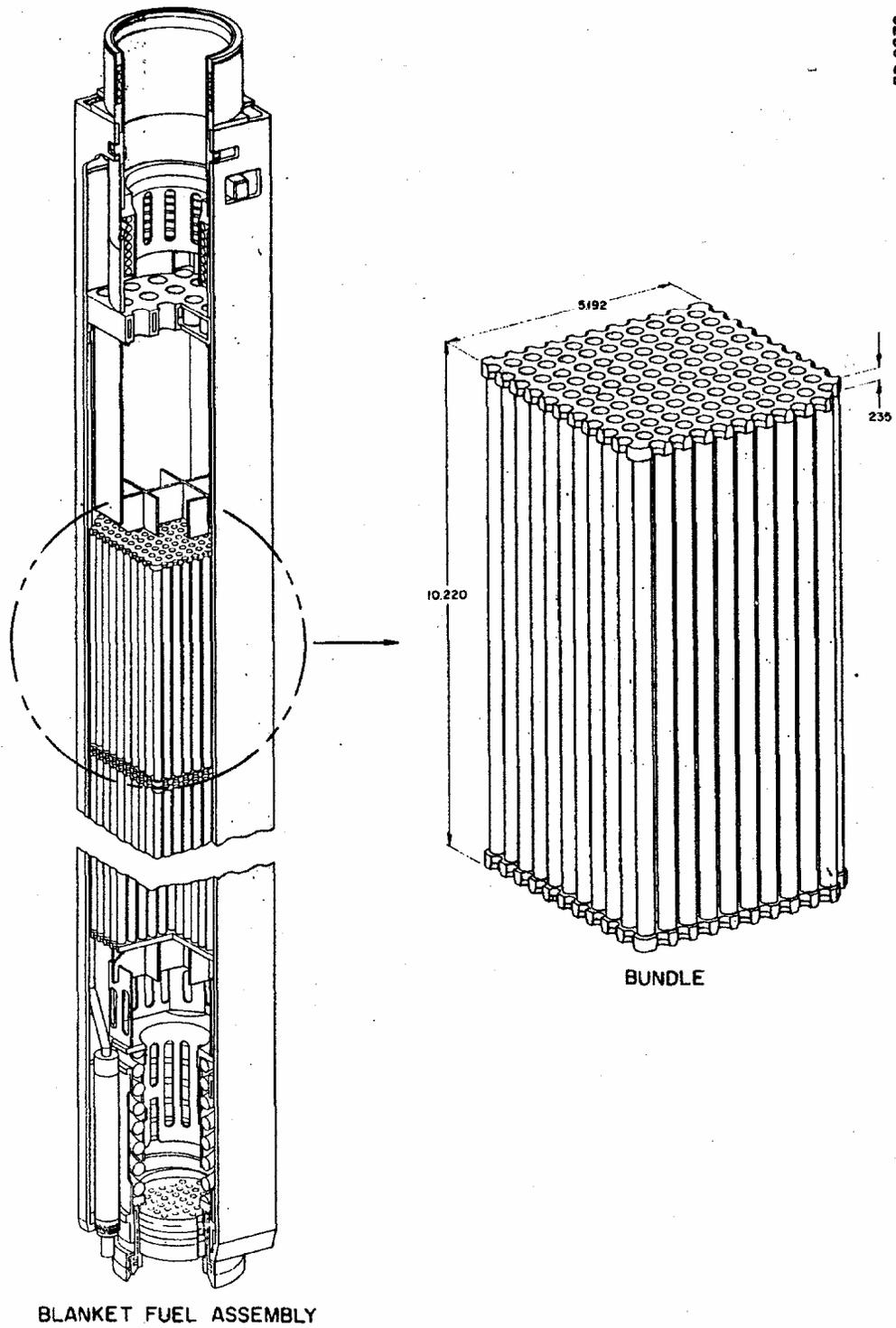
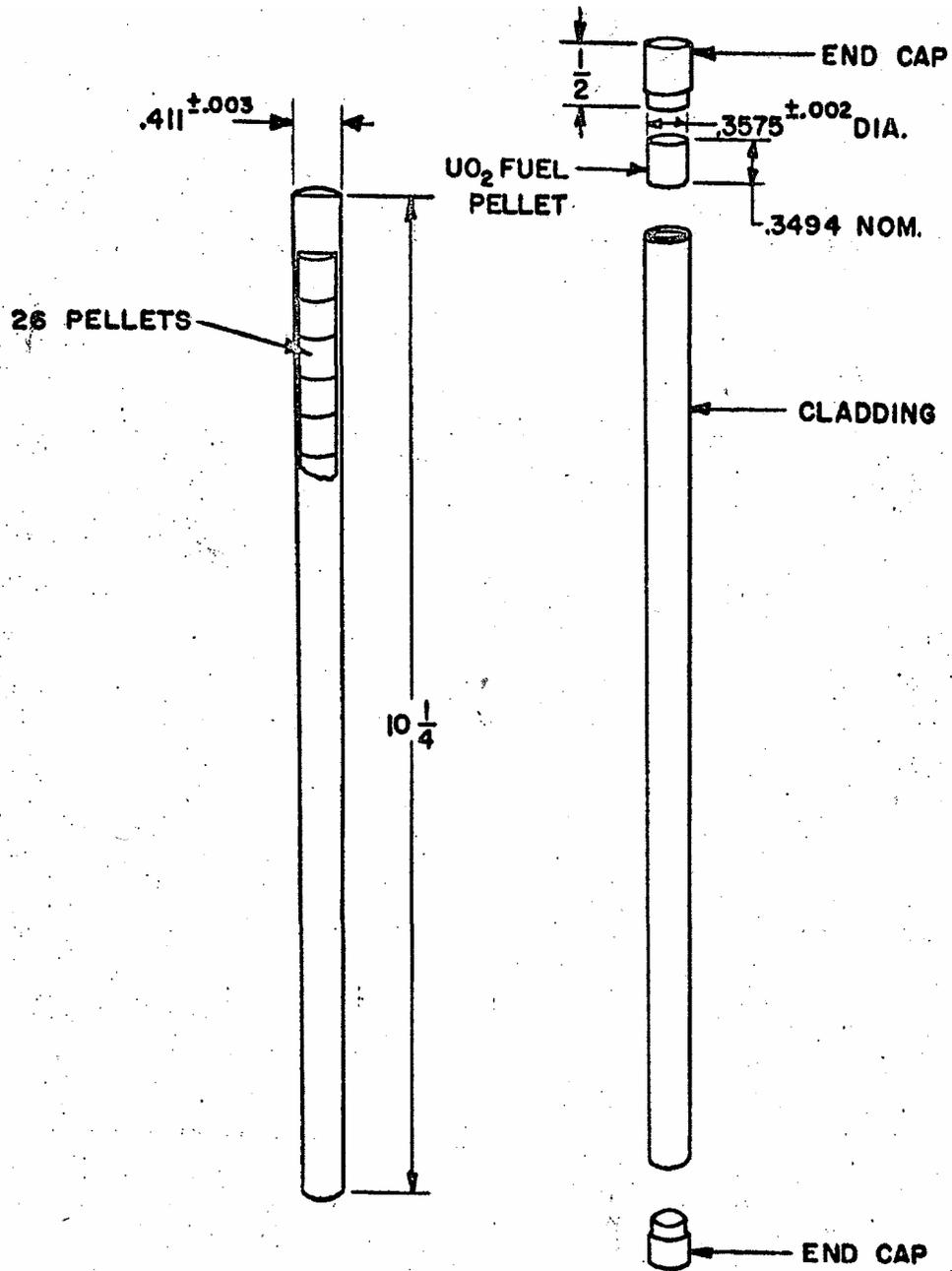


Figure 3. PWR-1 Blanket Assembly



PWR-1 UO₂ FUEL ROD

NOTE: DIMENSIONS ARE IN INCHES

Figure 4. PWR-1 Fuel Rod

Attachment 2

**Shippingport Core 1 Seed Fuel and SOAP Assemblies
Received at ECF**

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SHIPPINGPORT CORE 1 SEED FUEL AND SOAP ASSEMBLIES RECEIVED AT ECF

All Shippingport PWR seed fuel was received at ECF from the Duquesne Light Company. Core 1 included four refuelings where all seed fuel was replaced. There were 32 assemblies of seed fuel associated with each refueling. Each assembly contained four subassemblies. Each subassembly contained 15 fuel elements. The SOAP-I and SOAP-II were special seed fuel test assemblies. "Element" quantities refer to the total mass of uranium. "Isotope" quantities refer to total mass of Uranium-235. The serialized fuel accountability transfer transactions are referenced.

<u>Date</u>	<u>Fuel Received at ECF</u>	<u>Quantity</u>	<u>Reference</u>
5/5/60	1 Expended Seed assembly from Core I, Seed 1 of the Shippingport Atomic Power Station (SAPS)	1,732 g Element 1,416 g Isotope	DUQ-WEI-4
7/22/60	1 Expended Seed Assembly from Core I, Seed 1 of SAPS.	1,732 g Element 1,416 g Isotope	DUQ-WEI-5
2/20/61	16 Expended Seed Assemblies from Core I, Seed 1 of SAPS.	27,720 g Element 22,661 g Isotope	DUQ-WEI-6
3/31/61	14 Expended Seed Assemblies from Core I, Seed 1 of SAPS.	24,257 g Element 19,829 g Isotope	DUQ-WEI-7
11/16/61	16 Expended Seed Assemblies from Core I, Seed 2 of SAPS.	31,128 g Element 24,619 g Isotope	DUQ-WEI-11
12/15/61	16 Expended Seed Assemblies from Core I, Seed 2 of SAPS.	31,128 g Element 24,619 g Isotope	DUQ-WEI-13
3/13/63	16 Expended Seed Assemblies from Core I, Seed 3 of SAPS.	31,815 g Element 23,720 g Isotope	DUQ-WEI-15
6/6/63	14 Expended Seed Assemblies from Core I, Seed 3 of SAPS.	27,838 g Element 20,755 g Isotope	DUQ-WEI-16
7/25/63	2 Expended Seed Assemblies from Core 1, Seed 3 of SAPS	3,977 g Element 2,965 g Isotope	DUQ-WEI-18
5/25/64	Receipt of PWR-1 SOAP II fuel from Duquesne.	1,011 g Element 914 g Isotope	DUQ-WEI-20
12/23/64	4 Expended Seed Assemblies from Core 1, Seed 4 of SAPS.	8,093 g Element 6,502 g Isotope	PAB-PZB-1
	SOAP-I (Subassembly No. x)	760 g Element 477 g Isotope	
3/8/65	12 Expended Seed Assemblies from Core 1, Seed 4 of SAPS.	24,280 g Element 19,506 g Isotope	PAB-PZB-2
3/26/66	16 Expended Seed Assemblies from Core 1, Seed 4 of SAPS.	32,373 g Element 26,008 g Isotope	PAB-PZB-3

Summary Core 1 Received at ECF

<u>Seed 1</u>	32 Seed Assemblies Received	55,441 g Element 45,322 g Isotope
<u>Seed 2</u>	32 Seed Assemblies Received	62,256 g Element 49,238 g Isotope
<u>Seed 3</u>	32 Seed Assemblies Received	63,630 g Element 47,440 g Isotope
<u>Seed 4</u>	32 Seed Assemblies Received	64,746 g Element 52,016 g Isotope
<u>SOAP-I</u>		760 g Element 477 g Isotope
<u>SOAP-II</u>		1,011 g Element 914 g Isotope
<u>Total</u>	128 Seed Assemblies Received & SOAP-I/SOAP-II Test Assemblies	247,844 g Element 195,407 g Isotope

Attachment 3

**Shippingport Core 1 Blanket Fuel (Natural Uranium) Received at
ECF**

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SHIPPINGPORT CORE 1 BLANKET FUEL (NATURAL URANIUM) RECEIVED AT ECF

Shippingport PWR irradiated blanket fuel was primarily received at ECF from the Duquesne Light Company. Core 1 included three refuelings where portions of the blanket fuel were replaced. A final defueling included all the blanket fuel being replaced. There were 113 blanket assemblies contained in Core 1. Each blanket assembly contained seven fuel bundles. Each fuel bundle contained 120 fuel rods. "Element" quantities refer to the total mass of uranium. "Isotope" quantities refer to total mass of Uranium-235. The serialized fuel accountability transfer transactions are referenced.

<u>Date</u>	<u>Fuel Received at ECF</u>	<u>Quantity</u>	<u>Reference</u>
2/4/60	Receipt of one Irradiated Fuel Bundle from Reactor at Shippingport Atomic Power Station (SAPS). Bundle is from Original Blanket Assembly No. 031.	16 Kg Element 0.081 Kg Isotope 37 g Plutonium	DUQ-WEI-1
2/12/60	Receipt of 1 Irradiated Blanket Assembly from Reactor at SAPS.	112 Kg Element 1 Kg Isotope ^(a) 261 g Plutonium	DUQ-WEI-2
2/15/60	Receipt of 1 Irradiated Fuel Bundle from Reactor at SAPS.	16 Kg Element 0.081 Kg Isotope 37 g Plutonium	DUQ-WEI-3
9/22/61	Receipt of 1 Irradiated Blanket Assembly from Reactor at SAPS.	112 Kg Element 0.372 Kg Isotope 501 g Plutonium	DUQ-WEI-8
10/16/61	Receipt of 1 Irradiated Blanket Assembly from Reactor at SAPS.	112 Kg Element 0.372 Kg Isotope 501 g Plutonium	DUQ-WEI-9
11/24/61	Receipt of 1 Irradiated Blanket Assembly from Reactor at SAPS.	112 Kg Element 1 Kg Isotope ^(b) 501 g Plutonium	DUQ-WEI-12
1/21/63	Receipt of Irradiated Blanket Assembly from Reactor at SAPS.	111 Kg Element 0.339 Kg Isotope 525 g Plutonium	DUQ-WEI-14
6/6/63	Receipt of 2 Irradiated Blanket Assemblies from Reactor at SAPS.	223 Kg Element 1 Kg Isotope ^(c) 208 g Plutonium	DUQ-WEI-17
4/3/64	Receipt SABRE Assembly	87 Kg Element 1 Kg Isotope ^(d) 208 g Plutonium	DUQ-WEI-19
7/21/64	Receipt of two PWR Core 1 fuel bundles from Bettis. (ref. values from DUQ-WEB-16)	31.6 Kg Element 0.08 Kg Isotope 165 g Plutonium	PZA-PZB-1

12/23/64	Receipt of 10 irradiated Blanket Fuel Assemblies with 7 original Fuel Bundles and 1 irradiated Blanket Fuel Assembly with 6 original Fuel Bundles and 1 unirradiated Fuel Bundle containing Normal Uranium.	1204 Kg Element ^(e) 3 Kg Isotope ^(f) 6263g Plutonium	PAB-PZB-1
3/8/65	Receipt of 4 irradiated Blanket Fuel Assemblies containing depleted Uranium and Plutonium.	412 Kg Element 1 Kg Isotope ^(g) 2143g Plutonium	PAB-PZB-2
6/18/66	Receipt of 16 PWR-1 irradiated Blanket Fuel Assemblies containing Depleted Uranium and Plutonium from Duquesne Light Co.	1,781 Kg Element 6 Kg Isotope 9392g Plutonium	PAB-PZB-4

Notes:

- (a) Value was likely rounded up. A more likely quantity is 0.567 Kg (based on 0.081 Kg per fuel bundle and each assembly containing 7 bundles – see 2/4/60 shipment)
- (b) Value was likely rounded up. A more likely quantity is 0.372 Kg (see 10/16/61 shipment)
- (c) Value was likely rounded up. A more likely quantity is 0.678 Kg (based on 0.339 Kg per fuel bundle - see 1/21/63 shipment)
- (d) Value was likely rounded up. If same ratio of “Isotope” to “Element” as 2/60 shipments is used (which is the highest such ratio), the quantity would be 0.44 Kg.
- (e) Total does not include unirradiated fuel bundle.
- (f) Total was likely rounded down. A more likely quantity is 3.08 Kg (based on same ratio of “Isotope” to “Element” as 7/21/64 shipment).
- (g) Total was likely rounded down. A more likely quantity is 1.043 Kg (based on same ratio of “Isotope” to “Element” as 7/21/64 shipment).

Summary PWR-1 Blanket (Natural Uranium) Fuel Received at ECF

Total (Mass) PWR-1 Blanket Fuel Received	4329.6 Kg Element 15.325 Kg Isotope 20.742 Kg Plutonium
Best Estimate Total Mass of Isotope (based on notes on table)	13.505 Kg Isotope